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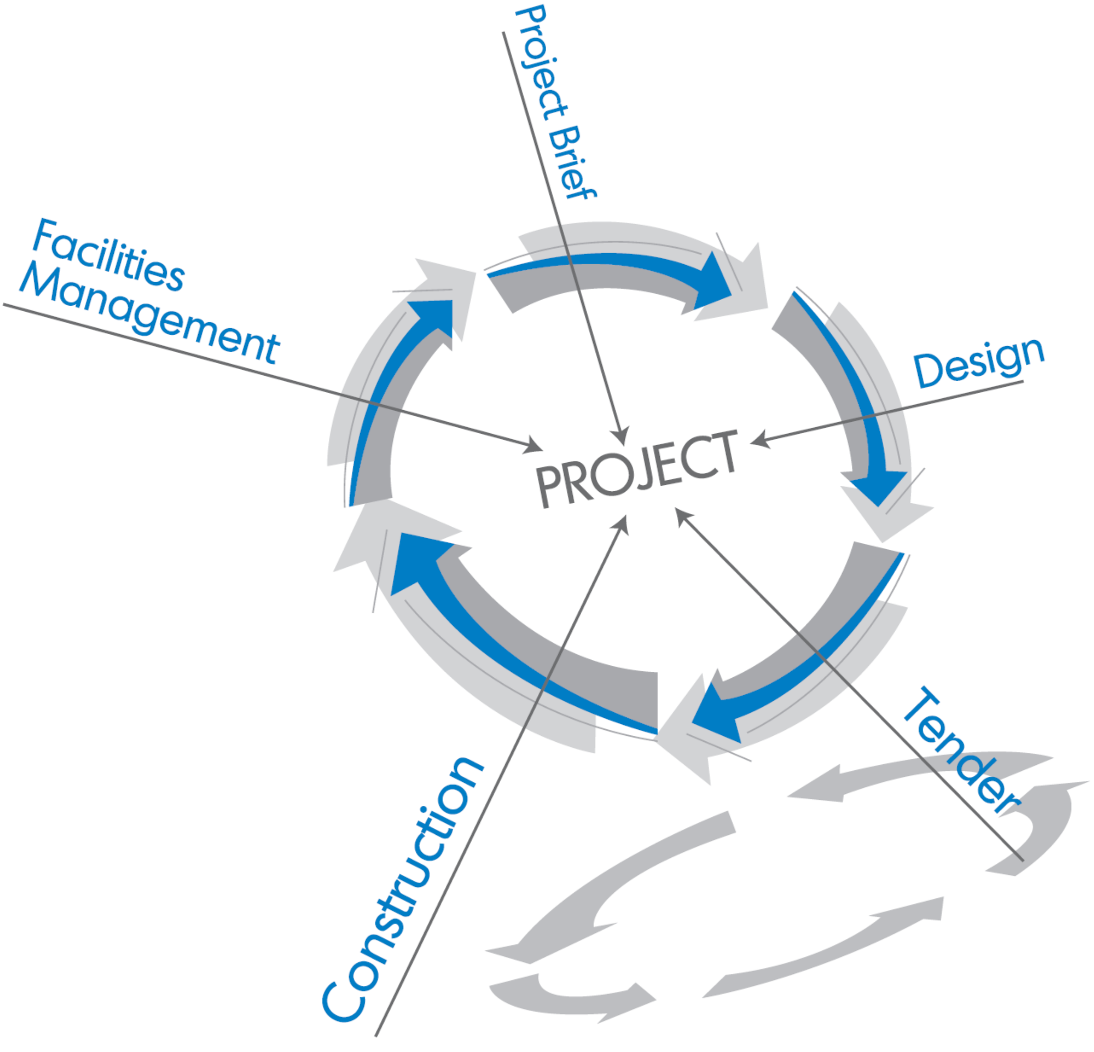

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Contents

Editorial Advisory Board

Editorial

Welcome from the Editors

Welcome to the twenty-forth (24th) issue of Malaysian Construction Research Journal (MCRJ). In this issue, we are pleased to include eight papers that cover wide range of research area in construction industry. The editorial team would like to express our sincere gratitude to all contributing authors and reviewers for their contributions, continuous support and comments.

In this issue:

Kasbi Basri et al., studied the peat shear wave velocity by using 1-D multichannel analysis of surface waves. The in-situ density was determined through the peat sampler, while the shear modulus was estimated using empirical formula. The results indicated that the peat shear wave velocity was affected by the changes in peat soil density, while the peat density was governed by the depth. The peat shear modulus value was directly proportional to the peat shear wave velocity.

Ahmad Faiz Abd Rashid and Sumiani Yusoff, presented a Life Cycle Assessment (LCA) approach to assess Global Warming Potential (GWP) of a residential building in Malaysia. The results of the study are elaborated further in this paper. The findings can serve as the benchmark for LCA for local buildings.

Mustafasanie M. Yussof and Muhammad Fais Haizad Ismail, compared the performance of glass fibre and T-beams under two loading conditions – static and cyclic loads, as well as the ultimate breaking load by adopting a three-point flexure testing method. The results showed that the cyclic loads influence the strength of the glass structures.

Nik Zainab Nik Azizan et al., analysed the structural performance of a dam under repeated near field and far field seismic loadings. The dam safety throughout its design life is also analysed by considering the material impact on the chemical factors and mechanical loadings as the age of the concrete reach up to 100 years. The performance of the dam for 50 and 100 years after the construction is also studied.

Nathaniel Ayinde Olatunde et al., assessed the exhibited team role of construction team members in selected higher institutions in Nigeria. The study aims to improve construction project delivery through the selection and composition of appropriate team members. The findings of the study are discussed in this paper.

Sakhiah Abdul Kudus et al., described a study of vibration characteristics of square and rectangular plate structures undergoing corrosion and loss of section problem. A finite element analysis utilising Abaqus code is adapted to model the problem, comparing the natural frequency and mode shape of an undamaged and healthy plate (baseline model) with a damaged model. The mode shape is then further evaluated to study its sensitivity towards the presence of damage.

Kim Hai Tey et al., explored team integration in the construction industry. A newly conceptualised model, 4Cs (Communication, Coordination, Cooperation and Collaboration) has been developed and it can serve as a framework for stakeholder to organise project teamwork as well as act as a catalyst to improve project performance.

Renard Yung Jhien Siew, evaluated the perception of practitioners regarding the different financing options available for retrofit projects by conducting a semi-structured interview with 16 experienced practitioners in Malaysia. From the interviews, some key success factors that influence the decision to embark on a retrofit project are identified, and it was found that Energy Performance Contracting (EPC) was the preferred form of alternative financing.

Editorial Committee

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ESTIMATION OF SHEAR WAVE VELOCITY USING 1-D MULTICHANNEL ANALYSIS OF SURFACE WAVES (MASW) AND SHEAR MODULUS OF PEAT

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Abstract
In geotechnical earthquake engineering problems, dynamic soil properties determination is a critical task. Shear wave velocity (Vs), and shear modulus (G) are fragments of dynamic soil properties. This study focused on the peat shear wave velocity determination using 1-D multichannel analysis of surface waves, the in-situ density using the peat sampler and the shear modulus estimation using empirical formula. The study was conducted at Parit Nipah, Johore and Penor, Pahang as it contains a large composition of peat. The result of the study indicates that, the peat shear wave velocity ranged from 30.4 m/s to 43.8 m/s for Parit Nipah and 43.4 m/s to 105.8 m/s for Penor. While the peat density ranged from 1.00 g/cm³ to 1.24 g/cm³ for Parit Nipah and 0.72 to 1.36 g/cm³ for Penor. The peat shear modulus, Gmax for Parit Nipah ranged from 736.0 kPa to 2589.6 kPa and 1474.7 kPa to 11265.0 kPa for Penor. The results indicate that the peat shear wave velocity was affected by the changes in peat soil density, while the peat density was governed by the depth. The peat shear modulus value was directly proportional to the peat shear wave velocity. Finally, the slight variation in results obtained might be due to the heterogeneity of peat.

INTRODUCTION

In geotechnical earthquake engineering problems, dynamic soil properties determination is a critical task, especially when it involves problematic soil such as peat soil. Peat is a representative material of soft soils. According to Zainorabidin et al. (2007) peat is characterized with high water content (>200%), high compressibility, high organic content (>75%), low shear strength (5-20kPa) and low bearing capacity (<8 kN/m^2). Due to this unique characteristic of peat soil, it has become a major problem to do construction in this problematic soil. Peat is well known to deform and fail under light surcharge load (Sha'abani and Kalantari, 2012). Therefore, studies need to be done on peat soil characteristics to provide better solutions and to ease construction work on peat. According to Kishida et al. (2009) research on dynamic properties of highly organic soil is limited which only consist of Union Bay in Washington State (Seed and Idriss, 1970), Queensboro Bridge in New York (Stokoe et al., 1994), Sherman Island in California (Boulanger et al., 1998; Wehling et al., 2003), Mercer Slough in Washington State (Kramer, 2000), and Ojiya City in Japan (Tokimatsu and Sekiguchi, 2007). This study focused to determine the dynamic behaviour of peat soil such as the shear wave velocity and shear modulus. The peat soil in-situ density was also determined.

Shear wave velocity (Vs) is the best indicator to determine the shear modulus which is one of the most critical engineering parameters that directly linked to a material's stiffness (Park et al., 2007). According to Yordkayhun et al. (2014), shear wave velocity is a quantitative parameter describing the dynamic properties of soils. The data regarding soil properties were conventionally collected by coring. However, multichannel analysis of surface waves (MASW) can support these point data in more time efficient manner and intrusive method.

Multi-channel Analysis of Surface Waves (MASW) is a fast method of evaluating near-surface shear wave velocity profile (Park et al., 1997). This method is intrusive and more economical compared to other seismic methods in terms of field operation, data analysis and overall cost (Park et al., 2007). MASW is a seismic exploration method evaluating ground stiffness in 1D, 2D, and 3D formats for various types of Geotechnical engineering projects. Since its first introduction in the late 1990s by the Kansas Geological Survey (Park et al., 1999), it has been utilized by many practitioners and researched by many investigators worldwide. The MASW exploits multichannel recording and processing techniques in order to solve the problem associated with the Spectral Analysis of Surface Waves (SASW) (Huang and Mayne, 2008). According to Xia et al. (2002), MASW is an environmentally-friendly method for estimation of shear-wave velocity with depth. It is also economically reliable compared to several other methods. In the matter of time for example, MASW method needed approximately a few minutes to obtain the data. There are two types of MASW methods, namely the active MASW method and passive MASW method (Park et al., 2007). Since the study only covers the range of less than 30 m depths, the active MASW method is more cost-effective and time efficient. The shear wave velocity obtained using the MASW method was used to estimate the shear modulus using empirical formula.

The formula used to compute the shear modulus needed the in-situ density of soil. Thus, the density was obtained on site using the peat sampler. The stainless-steel peat sampler is in fact a kind of gouge auger. The peat sampler is used to take a soil sample by manually pushing it into the soil. The sample containing part is a half cylinder. The peat sampler distinguishes itself from the standard gouge auger as its cone is massive. The peat sampler is only suitable for flabby and very soft soils (Eijkelkamp Agrisearch Equipment, 2014). The peat sampler is able to take a semi-disturbed samples from soft soils at predetermined depths.

EXPERIMENTAL

Site Description

The surface and subsurface condition of the study area affect the result obtained. The study area was located in a rural area of southern and East Malaysia (Figure 1). The location was situated in quaternary region, which consist of marine and continental deposits such as clay, silt, sand, peat with minor gravel. The land use for the site locations was for agricultural purposes which consist of palm tree and pineapple. According to the test done using the peat sampler, the peat soil layer thickness at Parit Nipah and Penor was 2.5 meter and 1.5 meter from surface respectively. Marine clay layer was found after the peat soil layer at both locations.

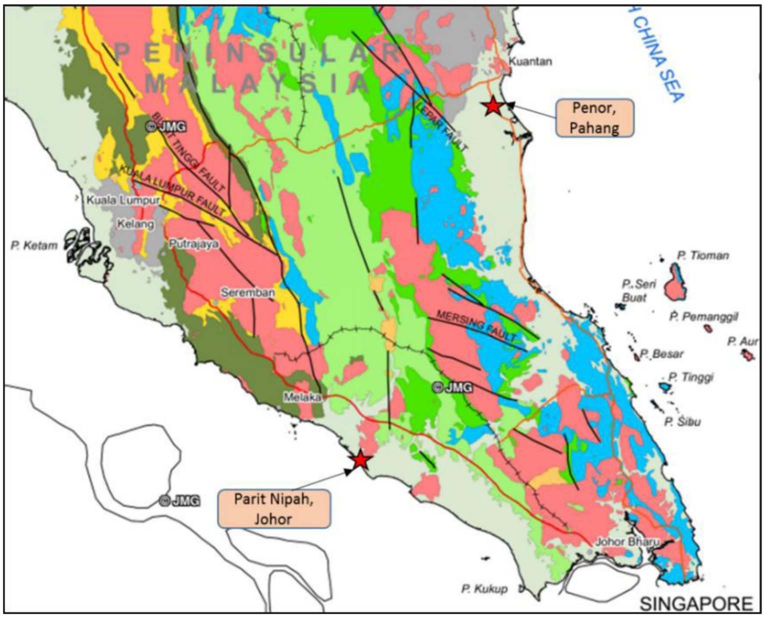

Figure 1. Study locations

Multichannel Analysis of Surface Wave (MASW)

The shear wave velocity profile was obtained using 1D MASW method. For data acquisition, 7 kg of sledge hammer was used as the source of seismic wave, 24 units of 4.5 Hz geophones were used as the sensor and ABEM Terraloc MK8 was used as a recorder. There are 5 array lines used in each location. In every line, 1-meter geophone spacing and 5-meter offset were used as shown in Figure 2. The gap between each array line was 0.5 meters and 5 shot points stacking were used for each line.

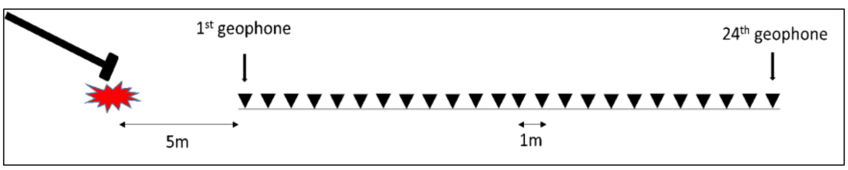

Figure 2. MASW configuration

For data analysis, two software, namely SeisImager and WaveEq were used to analyse the data. The SeisImager was used to pick the best pick point in the dispersion curve while the WaveEq was used to produce the 1D MASW model and generate the Vs profile. After data acquisition, the raw data obtained which is the phase velocity were adjusted to ensure the source offset, number of sensors and the sensor location was accurate. Then, the dispersion energy will be generated using the wave field transformation of the shot gather from time-space (t-x) domain to phase velocity-frequency (f-v) domain. Fourier transformation was applied to the time axis of shot gather and slant stacking with different slowness was applied to obtain the phase velocity for a particular frequency and the maximum stack amplitude is a result of the determined slowness.

Then, the process entered the critical path which was plotting the dispersion curve to create the initial Vs model. According to Yordkayhun et al. (2014), the dispersion curve was picked at the peaks of dispersion energy by considering the fundamental mode surface waves of the signal and their signal to noise ratios. The analysis of surface wave data generally assumes that a dispersion curve mainly consists of the fundamental mode. Finally, from the initial Vs model obtained, the inversion was done to seek the best Vs model that fits the dispersion curves of observed data. After the iterations, a final 1D velocity profile was obtained.

Peat Sampler

The in-situ peat density was obtained using the peat sampler. The samples were collected for every 0.5 meters until the clay soil was discovered. The sample's dimension was measured on site to minimize sample's disturbance. Then, the samples were brought to the lab in sealed plastic beg to be weighted in the lab. The volume and density were obtained using Equation 1 and Equation 2 respectively. Equation 1 was modified from the general volume formula to calculate the volume of sample in the half cylinder gouge auger. Three sampling points within the MASW array line were chosen for each location which was near the first geophone, midpoint and last geophone to obtain the average result and increased the accuracy of the data obtained.

$$V = \pi d2h/8 \qquad (1)$$

$$\rho = m/V \qquad (2)$$

Where d is diameter, h is height, V is volume, m is mass and ρ is density of soil

Empirical Formula

The peat shear modulus was obtained using the empirical formula. The shear wave velocity obtained was interpolated to obtain the value for every 0.5 meters depth. Then, the shear wave velocity and density was computed using Equation 3 to obtain the peat shear modulus. Based on the equation, the shear wave velocity is directly proportional to the shear modulus.

$$G_{max} = \rho V_s^2 \qquad (3)$$

Where G_{max} is small-strain shear modulus

RESULTS AND DISCUSSIONS

Shear Wave Velocity

From the MASW testing, the average value for all 5 array lines at both locations were taken and tabulated as shown in Table 1. From the table, a graph was plotted as shown in Figure 3.

Table 1. Average shear wave velocity for Parit Nipah and Penor

Depth (m)	Average shear wave velocity (m/s) for Parit Nipah	Average shear wave velocity (m/s) for Penor
0.0	38.3	105.8
0.5	39.6	86.6
1.0	43.8	51.8
1.5	42.7	43.4
2.0	42.1	59.3
2.5	30.4	77.9
3.0	27.2	–
3.5	31.1	–

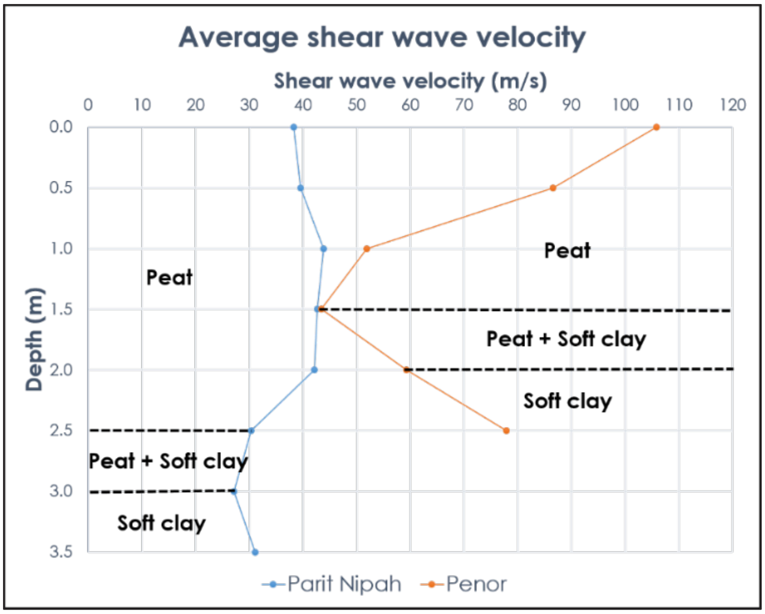

Figure 3. Graph of average shear wave velocity for Parit Nipah and Penor

The data obtained at both locations shows that the average value of peat shear wave velocity obtained for Parit Nipah, was in the range of 30.4 m/s to 43.8 m/s. While, the average peat shear wave velocity obtained for Penor, was in the range of 43.4 m/s to 105.8 m/s. From the graph (Figure 3), the shear wave velocity from both locations differs tremendously from the surface to the depth of 1 meter. This difference might be due to the presence of partially large wood fragments and tree trunks embedded on the soil surface at Penor which may contribute to the high shear wave velocity. As the shear wave velocity was high in hard material compared to soft material. While at the depth of 1 meter to 2 meters the values were almost similar. A slight variation of the shear wave velocity could be contributed by the heterogeneity of peat soil, which might suggest that the physical properties of peat soil changes in every depth. Since changes in the properties of the medium cause the change in speed of wave travels.

At the transition layer between peat and clay, the shear wave velocity at both locations behaved differently. By referring to the samples obtained using the peat sampler, the clay soil at Penor was more dense compare to clay soil at Parit Nipah. Therefore, this condition explained the high velocity obtained at the transition layer between peat and clay at Penor.

However, at Parit Nipah, the shear wave velocity at the transition layer between peat and clay decreased slightly. This behaviour might be due to the much less dense clay at Parit Nipah compare to Penor. The value obtained by Wehling et al. (2001) on peat shear wave velocity was in the range of 21 m/s to 30 m/s and 80 m/s to 165 m/s. While, Kishida et al. (2009) obtained the value of peat shear wave velocity ranged from 81 m/s to 87 m/s and 83 m/s to 90 m/s. Therefore, the result obtained had a good agreement with the value obtained by previous researchers.

Density

The results for the peat density for every 0.5 meters at both locations were as shown in Table 2. At each location, three sampling points were obtained and the average value was calculated and tabulated. A graph was plotted from the data obtained as shown in Figure 4.

Table 2. Average density for Parit Nipah and Penor

Depth (m)	Average Density (g/cm³) for Parit Nipah	Average Density (g/cm³) for Penor
0.0	1.00	0.72
0.5	1.21	1.09
1.0	1.14	1.22
1.5	1.24	1.36
2.0	1.21	1.42
2.5	1.22	2.15
3.0	1.44	–
3.5	1.55	–

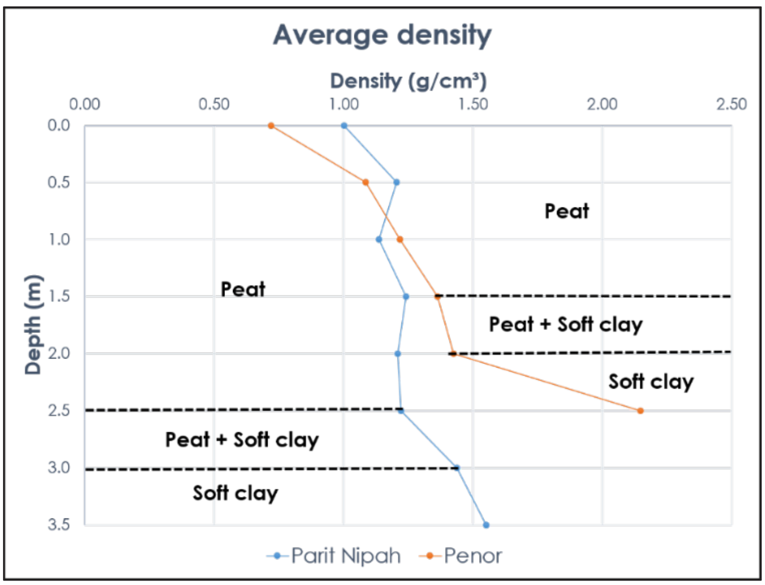

Figure 4. Graph of average density for Parit Nipah and Penor

The peat density for Parit Nipah and Penor increased simultaneously with depth. The value ranged from 1.00 g/cm³ to 1.24 g/cm³ for Parit Nipah and from 0.72 to 1.36 g/cm³ for Penor. The result shows that the density of peat soil at both locations was governed by the depth. The result obtained by Wehling et al. (2001) on peat density was in the range of 1.062

g/cm³ to 1.236 g/cm³. This concluded that the result obtained was similar with the previous researcher.

The result also shows that the changes in soil density affect the value of shear wave velocity. From the graph (Figure 4), the peat shear wave velocity at both locations increased slightly as the density increased. However, at Penor site, the top 1 meter of peat soil layer behave differently. The shear wave velocity decreased rapidly, although the density was increased. This situation might be triggered by the presence of large wood fragments and tree trunks embedded on the soil surface as mentioned earlier. The peat sampler confirmed the presence of large fibre within the 1meter depth of the peat soil layer at Penor. Some of the wood fragments and tree trunks were also visible as it was partially embedded in the soil.

At the transition layer between peat and clay at both locations, the density increased rapidly. This concludes that the clay soil has higher density compared to peat soil at both locations.

Shear Modulus Estimation

From the shear wave velocity and density obtained, the shear modulus was computed. The result was as shown in Table 3. From the table, a graph was plotted as shown in Figure 5.

Table 3. Shear modulus for Parit Nipah and Penor

Depth (m)	Parit Nipah min G_{max} (kPa)	Parit Nipah max G_{max} (kPa)	Penor min G_{max} (kPa)	Penor min G_{max} (kPa)
0	1318.5	1615.3	9530.2	11265.0
0.5	1708.3	2207.3	6851.9	7894.3
1.0	1993.1	2383.9	2104.0	2808.6
1.5	2067.8	2589.6	1474.7	3793.1
2.0	1878.4	2421.2	5182.9	6744.4
2.5	736.0	1652.2	8538.1	10895.7
3.0	985.3	1113.0	-	-
3.5	1333.3	1657.9	-	-

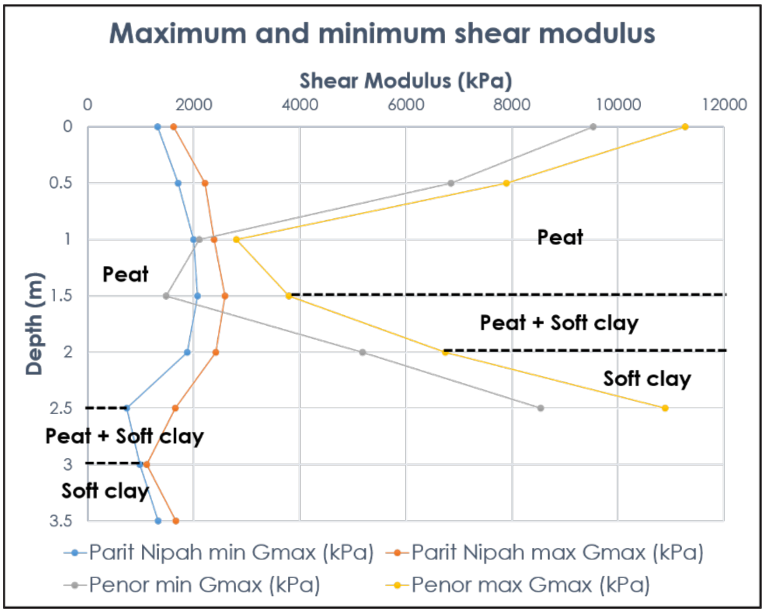

Figure 5. Graph of maximum and minimum shear modulus for Parit Nipah and Penor

From Table 3, the minimum G_{max} value of peat soil at Parit Nipah varies from 736.0 kPa to 2067.8 kPa, while the maximum G_{max} value varies from 1615.3 kPa to 2589.6 kPa. The minimum G_{max} value of peat soil at Penor varies from 1474.7 kPa to 9530.2 kPa, while the maximum G_{max} value varies from 2808.6 kPa to 11265.0 kPa. From the result obtained, it shows that the value of shear modulus is directly proportional to the shear wave velocity. The result obtained by Zainorabidin and Said (2015) was ranged from 1575 kPa to 3514 kPa and 385 kPa to 5117 kPa. The difference occurs might be contributed by the different composition of peat at different locations.

CONCLUSION

As a conclusion, the peat shear wave velocity was obtained ranged from 30.4 m/s to 43.8 m/s and 43.4 m/s to 105.8 m/s for Parit Nipah and Penor respectively. While the peat density was obtained ranged from 1.00 g/cm³ to 1.24 g/cm³ for Parit Nipah and 0.72 to 1.36 g/cm³ for Penor. Finally, the peat shear modulus, G_{max} ranged from 736.0 kPa to 2589.6 kPa for Parit Nipah and from 1474.7 kPa to 11265.0 kPa for Penor. The results obtained show that the shear wave velocity of peat soil was affected by the changes in soil properties such as density. On the other hand, the density changes with depth while the shear modulus value was directly proportional to the shear wave velocity value. Other than that, this study also had shown that the MASW method provides important soil parameters in time efficient manner and more economic along with large area coverage compare to conventional coring. This study also had provided engineer with some important parameters of peat soil that can be considered while designing or doing construction work in the peat soil area.

ACKNOWLEDGEMENT

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GLOBAL WARMING POTENTIAL OF A RESIDENTIAL BUILDING CONSTRUCTION IN MALAYSIA USING THE LIFE CYCLE ASSESSMENT (LCA) APPROACH

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Abstract
Building industry consumes substantial natural resources and produces considerable greenhouse gas emission. This paper presents a life cycle assessment approach to assess Global Warming Potential (GWP) of a residential building in Malaysia. The results show that building element that uses a cement-based material such as concrete contributed the highest GWP in comparison to other materials. In the construction phase, temporary timber formwork has the highest GWP. The results also show that the semi-detached house has higher GWP per m^2 compared to flats. The findings from this research can serve as the benchmark for LCA for buildings in Malaysia.

INTRODUCTION

Climate change and sustainable development are among major issues being discussed these days all over the world thoroughly. These issues demand improvement in government policies and industry standard. Building industry contributed considerably to the economy and social development but also responsible for excessive natural resource consumption and emission released (Arena and de Rosa, 2003). Recent research estimated that buildings responsible for 50% of Greenhouse Gas (GHG) emission and consume 40% of all primary energy globally (Asif et al., 2007).

Due to the increasing awareness of environmental issues, numerous studies have been conducted to reduce buildings' environmental impact including the implementation of Life Cycle Assessment (LCA) (Singh et al., 2011). Currently, LCA method is one of the assessment tools that being applied to assess the environmental impact thoroughly. LCA is globally accepted as a tool to improve the environmental impact of manufacturing processes and services in various industries and recently has been introduced to the building industry (Fava et al., 2009; Ortiz et al., 2009). LCA is a systematic analysis for quantifying industrial process and products by itemizing flows of energy and material use, wastes released to the environment and evaluating alternatives for environmental improvements (Fay et al., 2000; Guinée, 2012).

In Malaysia, the palm oil industry is the first sector to apply LCA as it was part of the requirement to export biodiesel to European countries (Ismail and Chen, 2010). Research on LCA has evolved to various industries in Malaysia since, ranging from electronics (Syafa et al., 2008), potable water production (Sharaai et al., 2009a, 2009b), electricity generation (Shafie et al., 2012), waste management (Onn and Yusoff, 2012) and buildings (Bin Marsono and Balasbaneh, 2015; Omar et al., 2014; Wan Omar et al., 2014; Wen et al., 2014).

The research on buildings primarily focused on the impact assessment of different materials and to highlight the benefit of integration of Industrialised Building System (IBS) in comparison to conventional construction system.

RESEARCH METHOD

This study follows the LCA method standardised by the ISO 14040 series. The ISO 14040 series describes the principal and framework for LCA which includes four stages namely goal and scope definition, Life Cycle Inventory (LCI), life-cycle impact assessment (LCIA) and interpretation (ISO, 2006a, 2006b).

Goal and scope definition

In this stage, it is important to select a suitable functional unit for the LCA study for validation in the interpretation stage. The functional unit selected in this study was 1 m^2 of Gross Floor Area (GFA), and the building lifespan was assumed to be 50 years as suggested by previous research (Abd Rashid and Yusoff, 2015). The case study is a semi-detached residential building, located in the district of Kuala Selangor, about 70 km from Kuala Lumpur. This building has an area of 218 m^2 with five bedrooms, two living rooms, a dining room, a kitchen, utility room and three bathrooms. It is two-storey high, and the primary structure is reinforced concrete with clay bricks as the building envelope as shown in Figure. 1.

The building life cycle was evaluated from cradle-to-gate within specific system boundaries outlined in Figure. 2. The site clearance works, external works and infrastructure works that cover the overall development were excluded.

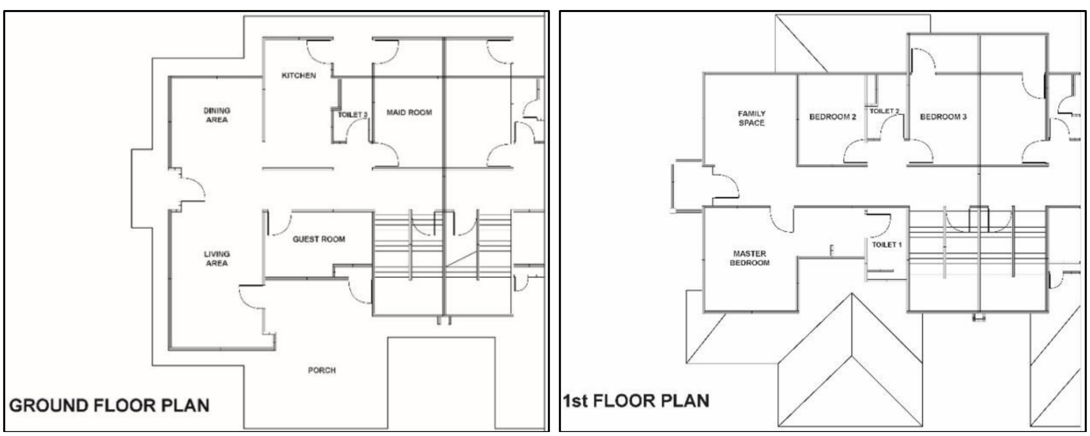

Figure 1. The building layout

The LCA modelling has been carried out in SimaPro V7.3.3 (PRé, 2015). Malaysia Life Cycle Inventory Database (MYLCID) was used in the LCI especially on raw materials such as cement and diesel to produce significant results for Malaysian scenario (MY-LCID, 2013). The Ecoinvent database was used due to limitation in the MYLCID. The database was adapted to Malaysian conditions by replacing the local electricity mix data set as suggested by Horváth and Szalay (2012).

Life Cycle Inventory

Pre-use phase

The data for LCI for the pre-use phase is obtained from the bill of quantities. The quantities are then divided into GFA of the building as shown in Table 1. Few assumptions have been considered due to the limitation of the databases as follows:

- An additional of 5% of material waste during construction was added as suggested by previous studies (Buchan et al., 2003; Rossi et al., 2012)
- The types and materials are limited to process data equipped in the MYLCID and Ecoinvent databases.
- Acrylic emulsion paint was substituted with alkyd paint due to the limitation in the databases.
- The transportation distances from the manufacturer to the construction site were assumed to be 300 km for all materials meanwhile, the distance is 50 km for ready-mix concrete, as suggested by (Wittstock et al., 2012).
- A 16-ton lorry was used to transport materials from manufacturers to site whereas a 24-ton ready-mix lorry was used to transport concretes.

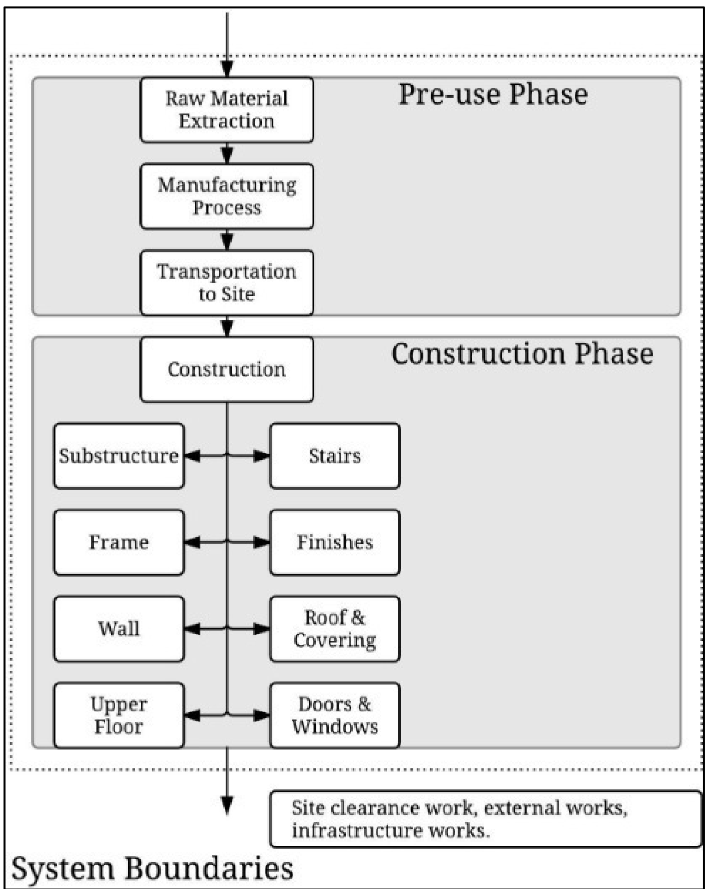

Figure 2. System boundaries of the life cycle model

Table 1. Quantity of materials used in the construction of the building

Item	Materials	Quantity	Quantity/m^2 GFA	Unit
A	*Substructure*			
	Excavation	153.50	0.70	m^3
	Hardcore	18.75	0.09	m^3
	Concrete Grade 7	8.50	0.04	m^3
	Concrete Grade 30	38.00	0.17	m^3
	Concrete Grade 35	18.50	0.08	m^3
	Reinforcement	6524.83	29.93	kg
	Formwork	5.91	0.03	m^3
B	*Frame*			
	Concrete Grade 30	31.95	0.15	m^3
	Reinforcement	4980.54	22.85	kg
	Formwork	7.46	0.03	m^3
C	*Upper Floor*			
	Concrete Grade 30	15.59	0.07	m^3
	Reinforcement	1222.54	5.61	kg
	Formwork	1.60	0.01	m^3
D	*Stairs*			
	Concrete Grade 30	4.50	0.02	m^3
	Reinforcement	375.00	1.72	kg
	Formwork	0.50	0.00	m^3
E	*Brick wall*			
	Clay brick			
	Half brick thick	474.00	2.17	m^2
	One brick thick	36.50	0.17	m^2
	Concrete block	0.02	0.00	m^2
F	*Roof and covering*			
	Concrete Grade 30	2.00	0.01	m^3
	Reinforcement	175.18	0.80	kg
	Formwork	0.26	0.00	m^3
	Wall plate	0.00	0.00	m^3
	Fascia board	0.00	0.00	m^3
	Painting wood	23.00	0.11	m^2
	Steel Roof Trusses	6812.50	31.25	kg
	Concrete roof coverings	272.50	1.25	m^2
G	*Finishes*			
	Cement screed	6.98	0.03	m^3
	Ceramic tiles	303.30	1.39	m^2
	Timber strip	53.70	0.25	m^2
	Plasterwork	29.20	0.13	m^3
	Painting	1635.80	7.50	m^2
	Ceiling	170.00	0.78	m^2

Construction phase

During construction, only three processes were taken into consideration specifically excavation works, transportation of the excavator to the construction site and temporary timber formwork. An excavator was assumed to be used during excavation works whereas, other installation works to be completed by manual labours. The transportation of the excavator was considered to be 50 km distance from the construction site by using a 40-ton low-loader. The formwork was expected to be used multiple times before disposal as suggested by Abdullah (2005).

Life cycle impact assessment (LCIA)

Blengini and Di Carlo (2010) suggested that the selection of indicators in the LCIA stage must be consistent with the ISO recommendations. Basically, there are two methods use in conducting LCIA, which is problem-oriented (midpoints) and damage-oriented methods (endpoint) (Abd Rashid and Yusoff, 2015). Midpoints are considered to be a point in the cause-effect chain of a particular impact category after the LCI before the endpoint (Bare et al., 2000). The midpoint assessment approach developed by Centre of Environmental Science (CML), Leiden University was used (Heijungs et al., 2009). Generally, common impact categories from CML 2001 were applied namely, global warming potential (GWP), acidification, ozone depletion (ODP) and eutrophication as suggested by Khasreen et al. (2009) although, for this research, only GWP will be assessed.

Interpretation

The final step in LCA is the interpretation of results. The results from the LCIA will be examined for robustness and sensitivity to inputs (Ochsendorf et al., 2011) and conclusions are drawn with reference to the goals and objectives of the LCA (ASTM Standards E1991-05, 2005). Subsequently, data validation will be conducted by comparing the results to other published research (Ochsendorf et al., 2011).

RESULTS AND DISCUSSION

The LCIA of materials used in the building was evaluated from cradle-to-gate i.e. from raw material extraction, manufacturing process and transportation to the site. Each building elements later converted to the functional unit of 1 m^2 of GFA. Figure 3 shows the LCIA of every element in the building.

Substructure elements have the highest impact for GWP (1.57E+02 kg CO2 eq) whilst the door is the lowest on all impact categories. Cement contributed the highest environmental impact due to high usage of concrete-based building elements such as in substructure, frame, stairs and finishes. Ceramic tiles for finishes and clay bricks for walls have also indicated high environmental impact compare to other elements. The construction process contributed only 4.70E+00 kg CO2 eq which largely contributed by the temporary formwork (3.74E+00 kg CO2 eq) as shown in Figure 4.

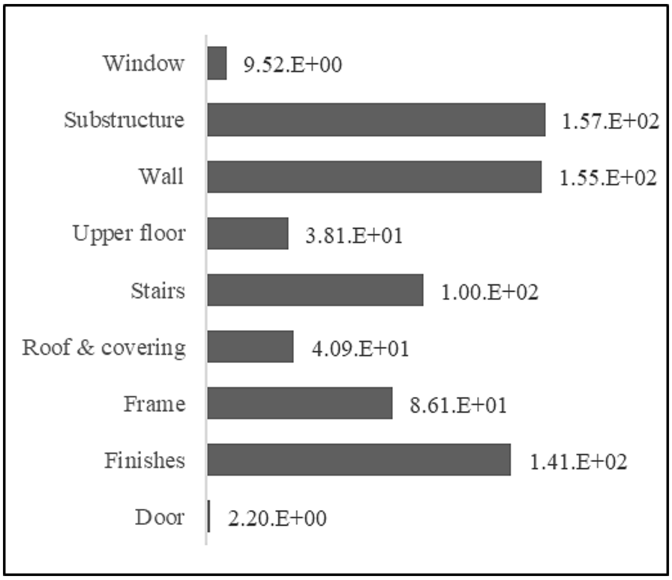

Figure 3. LCIA of the building using CML 2001 by building elements in pre-use phase

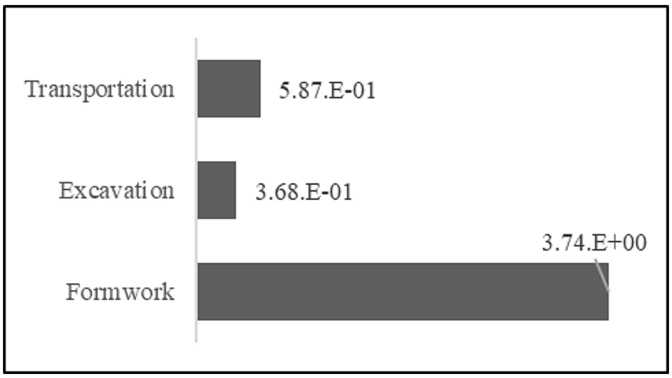

Figure 4. LCIA of the building using CML 2001 in the construction phase

Comparison with other studies

To complete the LCA process, the findings from this study will be compared to other published data for validation as shown in Table 2. For this purpose, only one research was used (Wen et al., 2014) as it is the only comparable data available in Malaysia with similar LCA method and functional unit. The GWP of the flats is much lower in comparison to this study by 3.91E+02 and 4.37E+02 kg CO2 eq.

Table 2. Comparison of GWP of the building with other research

Building	GWP (kg CO2 eq)	Gross Floor Area (m^2)	References
Flat (cast in situ)	3.44E+02	110.69	(Wen et al., 2014)
Flat (IBS)	2.98E+02	111.45	(Wen et al., 2014)
Semi-detached house	7.35E+02	218.00	This study

The lower impact from the flat due to the lower quantities per m^2 as most of the building elements such as substructure, walls, ceilings, floors, and roof were shared with multiples units. The specification for the flats was also not clearly defined explicitly. The different type of bricks, for example, may produce different results overall.

CONCLUSION

The results show that in general, the building elements related to the usage of concrete such as substructure, upper floor, stairs and frame have the highest impact per m^2 in comparison to other materials. Subsequently, clay bricks and ceramic tiles indicated high GWP while door and window have the lowest GWP. The construction has much lower GWP in comparison to the pre-use phase and most of the impact is contributed by temporary timber formwork. The results also show that the semi-detached house has a higher GWP per m^2 in comparison to flats due to most of the building elements are shared with multiple units. The findings from this study can serve as a benchmark for future LCA studies related to buildings in Malaysia.

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LOAD BEARING CAPACITY OF GLASS FINS AND T-BEAMS SUBJECTED TO STATIC AND CYCLIC LOADS

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Abstract
Nowadays there are examples of structures made of glass only. It is progressively being used in building construction as load bearing elements. Glass is brittle and has an unusual behaviour when loaded. The aim of this paper is to study the performance of glass fins and T-beams under two loading conditions namely, static and cyclic loads. The cyclic load that was controlled by constant displacement rate was applied for few loading stages. The displacement rate was increased by 0.5mm at each loading stage. Three-point flexure testing method was adopted to determine the ultimate breaking load of these glass structures. The ultimate bending strength of glass T-beam is approximately 74% higher than that of glass fin. The load-displacement response of both types of glass structures is non-linear. Under the combination of pre-cyclic and static loads, the bending strength of glass fin and T-beams is 40% and 24% lower than that of the glass structures under static load only, respectively. The bending strength of glass structures reduced significantly when the glass was initially loaded. From this study, it was found that the strength of the glass structures is influenced by the repetitive or cyclic loads.

Keywords: *Glass fin, Glass beam, bending strength of glass, static and cyclic loads*

INTRODUCTION

Nowadays, the concept of transparency has a great influence on architectural imagination which has lead to examples of structures made solely out of glass as shown in Figure 1 In order to improve the comfort of the occupants by increasing the quality of interior space and optimization of natural resources, it is necessary to conceive a building with an interactive envelope such as glass (Savic et al., 2013). However, the performance of glass as load bearing element still needs to be further understood. The compressive strength of glass is significantly higher than its tensile strength, but the glass tends to fail in brittle manner (Aiello et al., 2011). Typically, the slenderness ratio of the structural glass member is large where the cross-sectional area of the glass structure is small compared to its length. These characteristics have made glass member sensitive to lateral torsional buckling which causes its strength to be far lower than the actual bending strength (Belis et al., 2003). Campione et al. (2013a) have reported that although the laminated glass continued to sustain the load as the first failure occurred, the load bearing capacity was reduced instantaneously after the peak load. In addition, the type of interlayer film of the laminated glass has a great influence on the load carrying capacity of glass member. Bernard et al. (2004) have developed a method to calculate the load bearing capacity of tempered flat glass beams. The method developed may help the design of dowel type joints for tempered glass structures used in buildings. Pandkhart (2005) adopted four-point bending method to investigate the load bearing capacity of glass panes. The experimental study was carried out to analyse the effect of tempering and influence of interlayer material and temperature on the structural behaviour of glass panes.

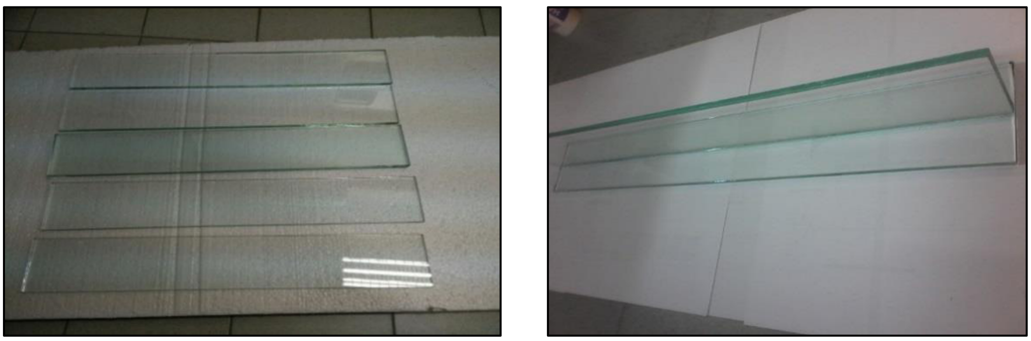
(a) (b)

Figure 1: (a) Glass fin systems (Enclos n.d.), (b) Glass fin and mullion of the Apple Store, New York (Apple store in New York n.d.)

Glass used as load bearing element such as slab and beam may subject to repetitive load. For example, peoples walking on glass floor panel applies a force at a step of frequency. Although the magnitude of force is small, walking induced repetitive loads on the glass floor panel. This action is then distributed with the same manner to the other supporting glass structure such as beam. Sglavo et al. (1997) have found that cyclic loading did not influence the ultimate strength of glass. In addition, the effect of cyclic loading in fatigue failure of glass remains unclear but the cause can be envisioned through its local structural change (Packard et al., 2008). However, Boxheimer and Hilcken (2011) has noted that the cyclic loading influences the flexural tensile strength of the glass. The strength of glass is reduced when the glass was initially preloaded. Campiano et al. (2013b) have studied the flexural behaviour of glass panel under two types of loading namely cyclic and monotonic loadings. The glass member under both loading conditions did not show cracks with glass fixings remain intact. However, Pankhardt (2005) found that the load bearing capacity of the structural glass of a column that has been initially subjected to cyclic loading was 30% lower than that under static loading. However, Tavares et al. (2015) have also reported that the glass suffers structural damage when subjected to cyclic loads. From the above review, it can be seen that previous researchers have reported that the behaviour and performance of glass structures is influenced by repetitive or cyclic loads. In order to further understand the effect of cyclic loading on load carrying capacity of glass structures, the load bearing capacity of glass fin and T-beams under static and cyclic loadings was studied in this study.

METHODOLOGY

Two types of glass beam were considered in this study namely fins and T-beams. The size of the glass fins was 500mm (length) by 75mm (depth) by 6mm (thickness). The T-beam was formed by two pieces of the glass fins which were fixed together by silicone sealant as shown in Figure 2. The glass beam specimen was positioned on two steel roller supports at 300mm apart. The distance between the centres of the steel roller support to the corner of the glass beam was 100mm. 3mm thick rubber strip was put between the steel roller and the glass specimens to prevent direct contact between both parts. Two sets of glass holder as shown in Figure 3 were fabricated and used to hold the specimen in position and in vertically straight position. Moreover, the glass holder prevented the glass from out-of-plane bending and torsional buckling when subjected to loading. The glass holder was attached to the metal base. Three-point flexural testing of glass fins and T-beams specimens under cyclic loading have been conducted by using INSTRON Universal Testing Machine as shown in Figure 4(a). The experiments have been conducted in the Heavy Structure Laboratory, School of Civil Engineering, Universiti Sains Malaysia. The test setup for three-point bending tests on the glass beam specimens is shown in Figure 4(b). The glass beams were tested under two types of loading condition namely static and cyclic loads. For every type of glass beams and loading conditions, three samples were prepared. Glass fin specimens subjected to static and cyclic loads are named as PS1 to PS3 and PC1 to PC3, respectively. While glass T-beam specimens subjected to static and cyclic loads are named as TS1 to TS3 and TC1 to TC3, respectively. In static test, the load was increased until the glass breaks. In cyclic load, a continuous quasi-static cyclic loading history could not be set on the available testing equipment. Thus, three-point flexure tests under cyclic loading were conducted phase by phase. The amplitude of cyclic loading was controlled by displacement. The displacement for each phase of the cyclic loadings was increased by 0.5mm. At each phase, the specimen was cyclically loaded for 100 cycles. The maximum applied load at failure applied on the beam specimens corresponding to load when the glass beams rupture was recorded in each loading phase.



(a) (b)

Figure 2. (a) Glass fins specimens, and (b) Glass T-beam specimen

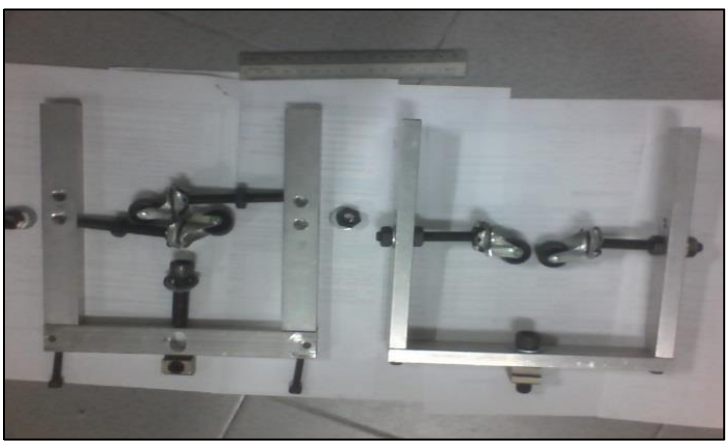
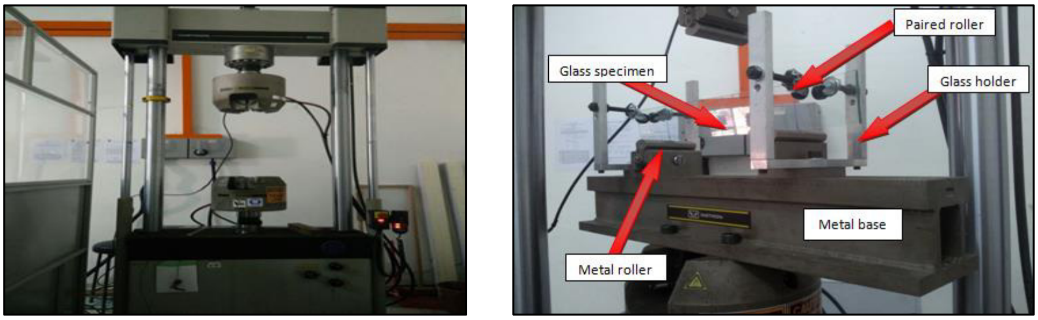


Figure 3. Glass holder components before and after assemblage



(a) (b)

Figure 4. (a) Universal testing machine used in this study, and (b) The glass specimen which was positioned on the steel roller and held by the glass holder

RESULT AND DISCUSSION

Crack Pattern of Glass Specimens under Loadings

All glass specimens were tested and loaded until failure. The maximum applied load at failure was recorded. Figure 5 shows the crack patterns for both glass fins and T-beam specimens. The crack pattern for all specimens was almost the same for both static and cyclic loading conditions. The glass cracked from the bottom part of the glass beam where the load was applied at the middle of the specimens. The glass breakage for both glass fins and T-beam happened abruptly without any warnings or signs. This is because the glass is a brittle material without plastic deformation characteristic.

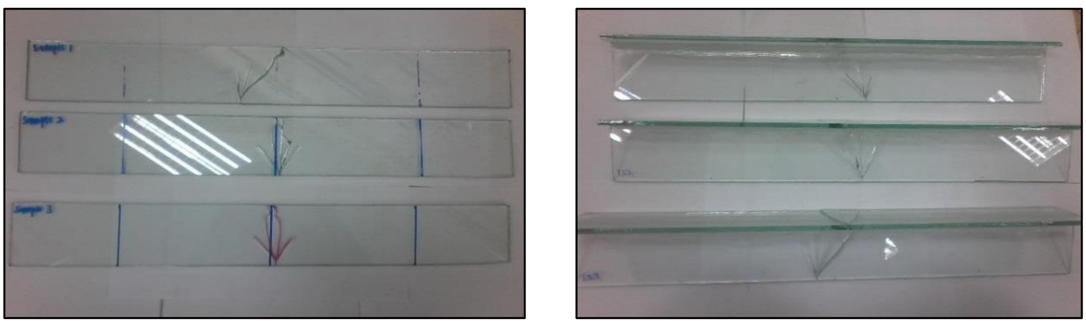


Figure 5. Failure of glass beams at maximum loading

Load Bearing Capacity of Glass Fins and T-beams under Static Loading

Figure 6 and 7 show the vertical displacement at the centre of glass fins and T-beams, respectively, under static loading. The load-displacement curves for both types of specimen were non-linear. With the absence of yield stress, glass breaks without yielding.

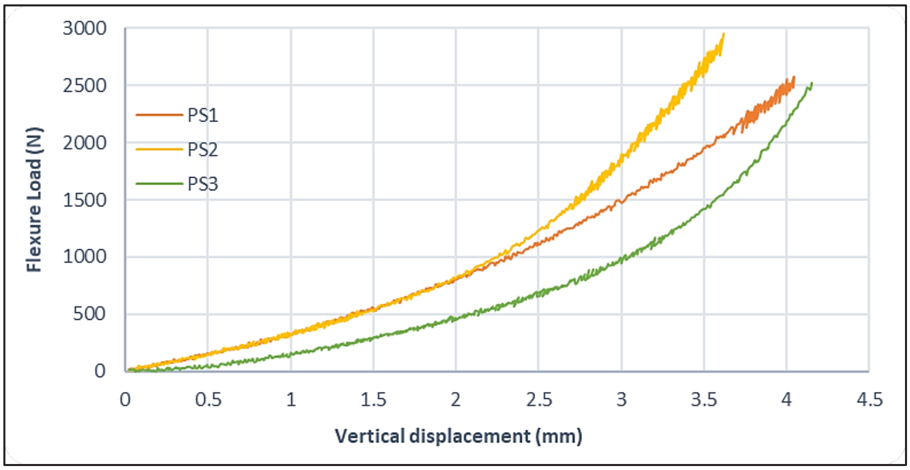


Figure 6. Flexure load - vertical displacement curve at the middle of glass fins specimens PS1, PS2 and PS3 under static loading.

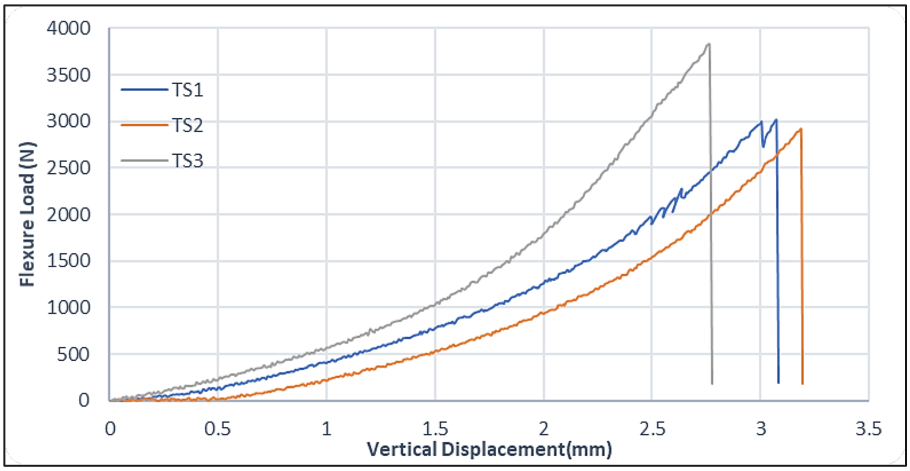


Figure 7. Flexure load - vertical displacement curves at the middle of glass T-beams TS1, TS2 and TS3 under static loading.

The ultimate breaking load and the ultimate bending strength for both types of specimens are tabulated in Table 2. The ultimate bending strength of the glass specimen is the highest stress experienced within the specimen before rupture and the value is calculated based on Equation 1.

$$\sigma = \frac{My}{I} = \frac{\left(\frac{PL}{4}\right)y}{I} \qquad \text{Equation 1}$$

where M is the maximum bending moment at the mid-span of the beam, y is the distance from the bottom fibre of the section to the centroid of the section, I is moment of inertia about the axis of the section that is perpendicular to the direction of loading and P is the maximum load applied on the specimen at rupture.

Table 2. The ultimate breaking load and bending strength of the glass fins and T-beams specimens under static loading

Specimens		Ultimate Breaking Load (N)	Average Ultimate Breaking Load (N)	Ultimate Bending Strength (N/mm^2)	Average Ultimate Bending Strength (N/mm^2)
	PS1	2580		34.4	
Fins	PS2	2910	2670	38.8	35.6
	PS3	2530		33.7	
	TS1	3010		56.5	
T-beam	TS2	2940	3270	55.2	61.5
	TS3	3870		72.7	

The average ultimate bending strength of glass T-beam under static loading is approximately 74% higher than that of glass fins. These results show that the glass T-beam has higher load bearing capacity as compared to that of glass fins. Moreover, the stiffness of the glass T-beam is greater than the stiffness of the glass fins. The ratio of force to deflection represents the stiffness of the element. By comparison, the vertical mid-span displacement of glass fins is greater than of glass T-beams. That makes the ratio of force to deflection for T-beam higher than that of glass fin. In other words, the stiffness of glass T-beam is higher than that of glass fins. This is true as the second moment of inertia of glass T-beam is greater than glass fin. It can be seen that the ultimate breaking load of the glass T-beams is higher than the glass fins. The results obtained in the static test were used for guidance to determine the increment of cyclic loading which was controlled by the displacement rate in the next series of test. Based on the results obtained, the glass fins and T-beams were deflected approximately between 3.5mm to 4.0mm and 2.7mm to 3.2mm at ultimate breaking load, respectively. These values were also used to predict the maximum vertical deflection of glass fins and T-beams at failure. Thus, the amplitude of displacement rate in each loading phase was increased by 0.5 mm.

Load Bearing Capacity of Glass Fins and T-beams under Cyclic Loads

Figures 8 and 9 show the load-displacement curves of glass fins and T-beams specimens. It can be seen that the relation between flexure load and vertical displacement is non-linear. The magnitude of load increased when the displacement rate was increased. The maximum load applied on the glass fins is lower than that of glass T-beams in each phase. This is because more force is required in deforming the glass T-beams at controlled displacement rate. The pattern of that response given by both types of glass beams under cyclic loading is the same with that of under static load. The ultimate breaking load of both types of glass beams under cyclic load is significantly lower than that under static load.

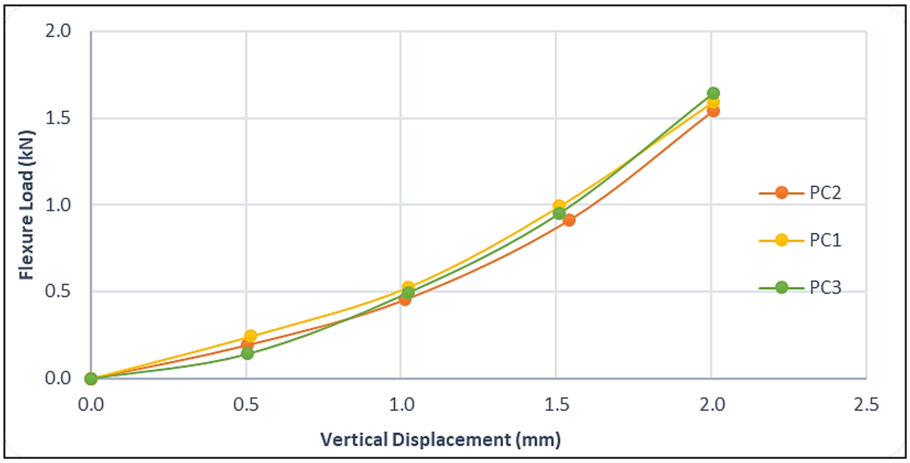


Figure 8. Flexure load - vertical displacement curves at the middle of glass fin specimens PC1, PC2 and PC3 under cyclic loading.

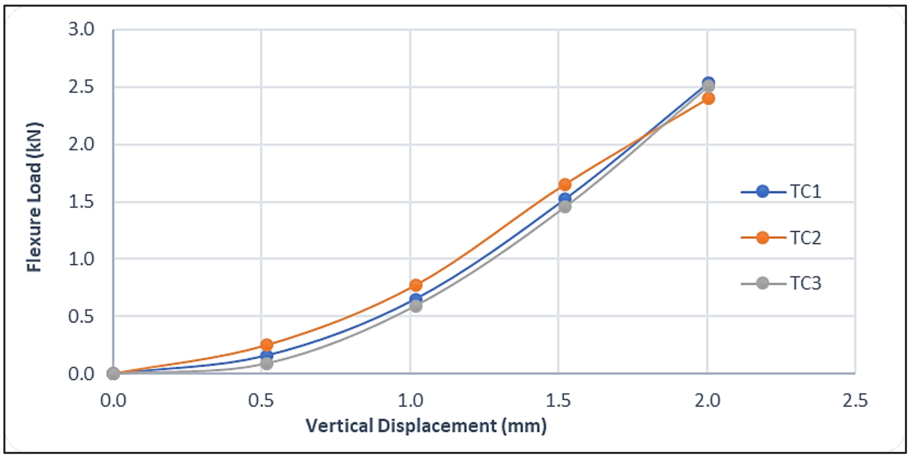


Figure 9. Flexure load - vertical displacement curves at the middle of glass fins specimens TC1, TC2 and TC3 under cyclic loading.

Table 3 summarizes the ultimate breaking load and bending strength of the glass fins and T-beams specimens under cyclic loading. The ultimate breaking strength of the glass T-beam is greater than that of the glass fins. This result is similar with the results obtained in static tests. However, the ultimate bending strength of the glass fins and T-beams specimens under cyclic loading is approximately 40% and 24% lower than that of the specimen under static loading, respectively. The reduction of the ultimate bending strength of glass might be due to the spread of flaws on glass surface which propagate abruptly under loads (LINDQvIST, 2013). There was a possibility of surface flaws developed on glass panel as it has been cyclically loaded. However, such statement is not observed in the experiments. From the results obtained in the experiments, the behaviour and strength of glass beams were found to be significantly influenced by even a small frequency of cyclic loading. The results show that it is important to understand the behaviour of glass under cyclic loads.

Table 3. The ultimate breaking load and bending strength of the glass fin and T-beam specimens under cyclic loading

Specimens		Ultimate Breaking Load (N)	Average Ultimate Breaking Load (N)	Ultimate Bending Strength (N/mm^2)	Average Ultimate Bending Strength (N/mm^2)
Fins	PC1	1594	1594	21.3	21.3
	PC2	1544		20.6	
	PC3	1644		21.9	
T-beams	TC1	2539	2484	47.7	46.7
	TC2	2405		45.2	
	TC3	2509		47.1	

CONCLUSION

The ultimate bending strength of glass fins and T-beams under static and cyclic loadings was determined from three-point bending test. The ultimate bending strength of the later specimens was greater than that of the former specimens. The crack pattern of the glass specimens under both static and cyclic loadings is almost the same for all specimens. The cyclic loading has significant impact on the performance of the glass specimens. The bending strength of glass was reduced under cyclic loading. Based on the cyclic tests, the bending strength of glass fins and T-beams was reduced by 40% and 24% of the corresponding static load test results when subjected to cyclic loading, respectively.

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SEISMIC PERFORMANCE OF A HYDROELECTRIC DAM UNDER REPEATED EARTHQUAKES

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Abstract
A large mainshock that can trigger a variety of aftershocks, including larger aftershocks, within a short period can potentially increase the cumulative damage on structures. This study is devoted to analyzing the structural performance of a dam under seismic loading. Seismic sequences characterized by the repetition of moderate and strong earthquakes are categorized into two parts: near field and far field. The distance of earthquake events from the epicenter less than 20 km is categorized as near field, whereas the distance of more than 20 km is considered far field. The effect of repeated near-field and far-field earthquakes on a concrete dam is investigated. The nonlinear seismic response of the dam differs because of the aging process. Chemical factors (humidity and liquidation process) and mechanical loadings, which are responsible for degrading aged concrete, are incorporated in this study. This study analyzes the dam safety throughout its design life by considering the repeated earthquake loading and material impact on the chemical factors and mechanical loadings as the age of concrete reach up to 100 years. The performance of the concrete dam for 50 and 100 years after the construction is studied.

Keywords: *Repeated Earthquake; Peak Ground Acceleration; Time History; Response Spectrum; Concrete Degradation*

INTRODUCTION

Dams are one of the largest structures constructed by humanity to serve different purposes, such as irrigation, hydroelectric power generation, flood control, and domestic and industrial water supply. Dams must be designed with a high safety factor to resist natural forces. Hydroelectric power is generated as water flows over the dam top into the downstream. The types of dams can be grouped according to the type of construction material, such as concrete and embankment dams. In Malaysia, 11 hydroelectric dams exist, including rockfill, concrete, and earthfill dams, as summarized in Table 1.

Sabah, Malaysia lies on the southeastern Eurasian Plate, which is bordered by the Philippine Plate and the Pacific Plate. The movement of the Philippine Plate and the Pacific Plate struck Sabah (Astro Awani, 2015) on 5 June 2015, when 6.0 magnitude earthquake struck Ranau, Sabah at depths of 10 and 15 km epicenter north of Ranau. Approximately 90 aftershock events were reported in Ranau by the Malaysian Meteorological Department (MMD, 2015) on 23 June. The magnitude for aftershocks ranged from 1.6 M to 5.2 M. The earthquake caused damage to 23 schools and other buildings. The water supply was disrupted and discolored in the Kundasang–Ranau area.

Every dam location has its unique geological characteristics. The high cost is required for carrying out a geological survey to understand the geological characteristics of an area before deciding on a suitable location to construct a dam. A dam is usually built in a valley area that can be at active fault areas, such as the Himalayas, Southwest China, Iran, Turkey, and Chile

(International Rivers, 2008). Dams damaged by earthquakes exceeding 6 M (Richter magnitude) occurred in Hsinfengking, China in 1962; Kariba, Zambia–Zimbabwe Border in 1963; Kremasta, Greece in 1966; and Koyna, India in 1967 (Gupta, 2002). The person involved in the design, construction, and operation of a dam should be sensitive to earthquake issues. The recent earthquakes in Malaysia occurred in Bukit Tinggi Pahang with 2.8 M in 2009 (The Sun Daily, 2009) and in Ranau with 6.0 M.

This study focuses on the performance of an aging concrete dam with repeated earthquakes. The importance of dynamic analysis for aged concrete is emphasized. Comparisons are presented for the dam responses under single, double, and triple earthquake events. Three types of models with different dimensions are appropriate for the dams in Malaysia. The behavior of the studied dam with aged concrete is studied by considering environmental factor (exposure to water), mechanical loading, and chemical reaction. The compressive strength gains for approximately 10 years for the ordinary concrete condition are determined.

Table 1 List of hydroelectric dams in Malaysia (Dahlen, 1993)

No.	Dam	Type of Dam	Height of Dam (m)	Operation (year)	Location
1	Bakun Dam	Rockfill dam	205	2011	Bakun River, Sarawak
2	Batang Ai Dam	Rockfill dam	85	1985	Batang Ai National Park, Sarawak
3	Bersia Dam	Concrete dam	33	1982	Gerik, Perak
4	Chenderoh Dam	Concrete dam	23	1930	Kuala Kangsar, Perak
5	Kenering Dam	Concrete dam	48	1986	Gerik, Perak
6	Odak Power Station	Earthfill dam	21		Cameron Highland
7	Pergau Dam	Earthfill dam	75	1996	Kuala Yong, Kelantan
8	Sultan Abu Bakar Dam	Concrete dam	40	1963	Cameron Highland
9	Sultan Idris II Power Station	Earthfill dam	45	1967	Cameron Highland
10	Sultan Mahmud Power Station	Rockfill dam	155	1987	Kenyir Lake, Terengganu
11	Temengor Dam	Rockfill dam	127	1978	Gerik, Perak

THEORETICAL FOUNDATION OF THE STUDY

Earthquakes that occur in fields close to a fault are known as near-field earthquakes. On the basis of the UBC-97 Code (International Code Council, 1997) refer to table 16-R for near-field earthquakes, the distance from the epicenter is considered less than 15 km. When the earthquake source is located near a structure when compared with the far field, the structure near the source causes damage to a great extent because the characteristic data change with distance (Heydari and Mousavi, 2015). The propagation of fault rupture toward a site at a high velocity causes most of the seismic energy from the rupture to arrive in a single or multiple large long-period pulses of motion, which occurs at the beginning of the record (Davoodi et al., 2013). Some dams in India are in highly seismic zones and are thus vulnerable to near-field ground motions (Mohan and Ramancharla, 2014). In this regard, the behavior of dams subjected to near-field ground motions should be considered because of their potential to cause more severe damage to the dams than the damage contributed by far-field ground motions (Zhang and Wang, 2013).

Seismic sequences characterized by the repetition of medium-strong earthquake ground motions occurring in a short time after other shocks have been observed in many parts of the world. Repeated earthquakes have a major impact on the behavior of reinforced concrete structures which cannot be predicted from a simple analysis (Abdelnaby and Elnashai, 2014). The index of damage for structures under repeated earthquakes can increase by five times or more compared with that under a single event (Hatzivassiliou and Hatzigeorgiou, 2015). The maximum story ductility demand can also be increased by 1.4 and 1.3 times when considering double and triple earthquake events (Faisal et al., 2013). The dam structure has already been damaged during the first individual seismic event, and the damage not yet repaired may increase the damage to the dam at the end of the seismic sequences (Zhang et al., 2013). Seismic sequences will lead to greater accumulated damage to the structure; and therefore, the seismic design should be given significant attention (Abdelnaby and Elnashai, 2014; Hatzivassiliou and Hatzigeorgiou, 2015; Faisal et al., 2013; Zhang et al., 2013).

Most hydroelectric dams made from concrete rather than embankment dam are usually built in an area with a larger amount of rock or earth. Dams in areas with limited sources of rock or earth are easy to build using concrete as a material. The nonlinear seismic response of dams is probably different because of the aging process (Nayak and Maity, 2013). The aged concrete will degrade because of the environmental factors and mechanical loadings that depend on the design life of the structure, in which increasing design life leads to decreasing degradation process (Gogoi and Maity, 2004). For the nonlinear seismic response of a concrete gravity dam, severe damage occurs to the structure with increasing age because of the degradation effects (Nayak and Maity, 2013).

CONCEPTUAL FRAMEWORK

This study considers three concrete dams with different dimensions. The first model is Koyna Dam, which is the largest hydroelectric dam in Maharastra, India operated since 1964. The dam experienced serious damage and power cut off to Bombay because of the 6.3 M earthquake in December 1967 (McCully, 1996). The dimension and properties of concrete dams are determined based on the models proposed by Nayak and Maity (2013). The dimensions of Models 1 and 2 are in accordance with the concrete gravity dams located in Malaysia. The age of the dams for Models 1 and 2 is between 30 and 85 years. The three models are considered to investigate the performance of the degradation of the dams' concrete under repeated earthquakes.

Figure 1 shows the conceptual framework developed to study dam performance under repeated earthquakes. The main parameters considered in this analysis are earthquake loading, static load, and elastic modulus of concrete caused by degradation. Earthquake loading is categorized into near field and far field, and each category includes single and repeated earthquakes. Repeated earthquakes are considered from real earthquake events and replicate single events with a gap time of approximately 100 s and a random combination of single earthquake events. The static load in this study includes the water condition of dams, that is, either empty reservoir, full reservoir, or flood reservoir.

However, this study only focuses on identifying the repeated earthquakes that occurred in the Mammoth Lake and considers two or three events for the three dams with different concrete ages. Mammoth Lake is selected in this study because of the data completeness of the continuous repeated events with the highest peak ground acceleration (PGA) of 0.315 g to 0.485 g. Future study will consider the performance of concrete dams under near-field and far-field earthquake events.

METHODOLOGY

Numerical Modeling

The equation of motion for dam–reservoir is given by;

$$M\ddot{u} + C\dot{u} + Ku = -Ma_g + F_h \tag{1}$$

where M is the mass matrix, K is the stiffness matrix of the structure, u is the displacement vector, $\dot{u}$ is the velocity vector, $\ddot{u}$ is the acceleration vector, a_g is the ground acceleration vector, and F_h is the nodal point force vector associated with hydrodynamic pressures. The damping matrix C represents the viscous damping in the structure.

The structural system considered in this investigation is analyzed using 2-D plane strain formulations. A constant longitudinal displacement corresponding to a rigid body translation and displacement linear in a direction perpendicular to the cross section of the dam and corresponding to rigid body rotations does not result in strain. The constitutive relation to elastic isotropic material can be written as;

$$\{\sigma\} = [C]\{\varepsilon\} \tag{2}$$

where

$$[C] = \frac{E}{(1-\mu)(1-2\mu)} \begin{bmatrix} (1-\mu) & \mu & 0 \\ \mu & (1-\mu) & 0 \\ 0 & 0 & (1-2\mu) \end{bmatrix} \tag{3}$$

The durability of concrete structures is progressively affected by the growth of damage. The increase in damage is due to time-variant external loading in addition to environmentally induced mechanisms, such as moisture and heat transport, freeze–thaw action, and dissolution processes, including calcium leaching, chemical expansive reactions, chemical dissolution, and reinforcement corrosion [4]. Concrete porosity is used when the coupling phenomena of chemical and mechanical damages on mechanical degradation are considered. Kuhl et al. (2004a, 2004b) proposed a procedure to estimate the total porosity as follows:

$$\phi = \phi_0 + \phi_c + \phi_m \tag{4}$$

where the total porosity is ϕ, the initial porosity is ϕ_0, the chemical porosity is ϕ_c, and the apparent mechanical porosity is ϕ_m. The consideration of apparent mechanical porosity ϕ_m is due to the opening and propagation of micro-cracks in the material. ϕ_m is defined as

$$\phi_m = [1 - \phi_0 - \phi_c] d_m \tag{5}$$

where d_m is the scalar degradation parameter. The strain-based exponential degradation function, as evaluated by Gogoi and Maity (2007), is

$$d_m = a_s - \frac{K_s}{K}\left[1 - \alpha_c + \alpha_c e^{\left(\beta_c[K^0 - K]\right)}\right] \tag{6}$$

where K^0 is the variable that represents the initial degradation status, and K is the internal variable defining the current degradation status. The internal variable K depends on the loading history of the material, in which K^0 is determined by f_t/E_0, where f_t is the static tensile strength, and E_0 is the elastic modulus of the undegraded material before any application of mechanical loading. β_c can be obtained experimentally (Kuhl et al., 2004b). Following Atkins (2006), we express the variation in the degradation index with time as

$$d_g = 1 - e^{(-t_a/\tau_a)} \tag{7}$$

where τ_a corresponds to the characteristic age or the design life of the structure, and t_a indicates the age at which the degradation index is determined. The relation between E and E_0 can be established as $E = (1 - d_g)E_0$. Here, E is the degraded elastic modulus caused by the porosity of concrete, and E_0 is the elastic modulus of concrete, considering strength gain at a particular age. Referring to Gogoi and Maity (2007), we define the variation in degradation with time as

$$E_m (1-\phi)^{-t_a/\tau_a} E_0 \tag{8}$$

The isotropic degradation index defined in Eq. (7) can be modified using Eq. (8) as

$$d_g = 1 - \frac{E_m}{E_0} \tag{9}$$

The static elastic modulus (SI units) of the concrete can be determined as

$$E_0 = 4733\sqrt{f(t_a)} \tag{10}$$

Where t is the age in years, and $f(t_a)$ is the gain in compressive strength. The gain in compressive strength of concrete was estimated by Washa et al. (1989) (in SI units) as follows:

$$f(t_a) = 3.27\ln(t_a) + 44.33 \tag{11}$$

In this study, three sections of dams with different sizes are considered. The first model is Koyna Dam, and the other two models differ in height. The height of Models 1 and 2 are 50 and 30 m respectively. The dimensions of structures with the water level are shown in Figure 2. The model characteristic, as presented in Table 2, is considered from past research (Nayak and Maity, 2013).

EARTHQUAKE GROUND MOTION

The strong-earthquake data are separated into two categories, near field and far field. The criteria for selecting repeated earthquake events are as follows: (a) the events more than two in the same direction and fault distance, (b) the magnitude is equal to or greater than 5.5, and (c) the PGA is equal to or greater than 0.15 g. Nine earthquake records based on these criteria are downloaded from the strong-motion database of the Pacific Earthquake Engineering Research Center (Ancheta et al., 2015) and Group for Research in Structural Engineering (2006), as shown in Table 3. This study focuses on the Mammoth Lake event because three events occurred on the same day and the high PGA of 0.485 g.

Figure 3 shows the time histories for acceleration records for the Mammoth Lake event under the near-field category by applying a time gap of 100 s between two respective seismic events. This gap has zero ground acceleration to cease the motion of any structure caused by damping before the action of the subsequent seismic event (Efraimiadou et al., 2013). The response spectrum of ground motion for 5% damping ratio is presented in Figure 4. The response spectrum for Mammoth Lake in combination with double and triple events shows a repeated earthquake higher than a single event. Table 4 shows the typical load combinations that are used in this study.

Table 2. Material properties

Modulus of elasticity (MPa)	Poisson ratio (υ)	Mass, ρ (kg/m^3)
31027	0.2	25.919

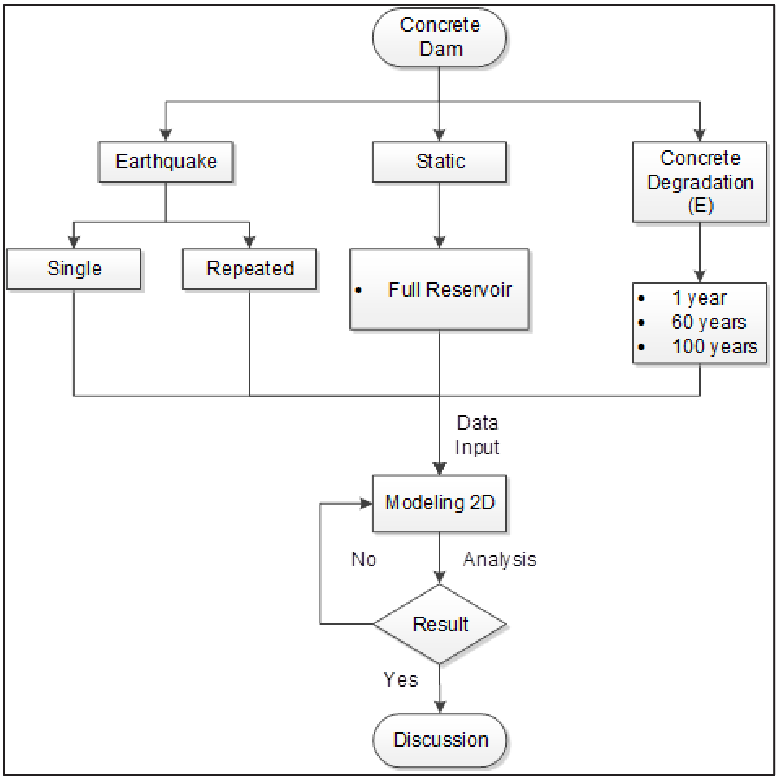

Figure 1. Conceptual framework

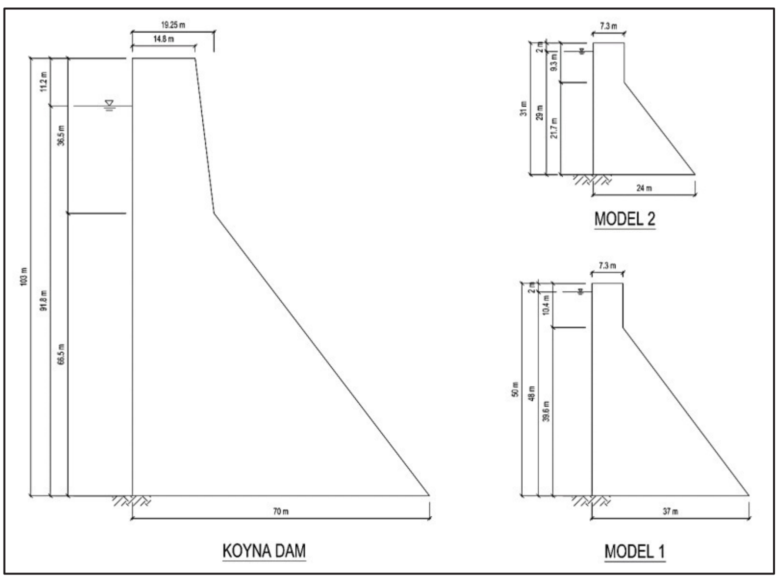

Figure 2. Cross sections of Koyna Dam, Model 1, and Model 2

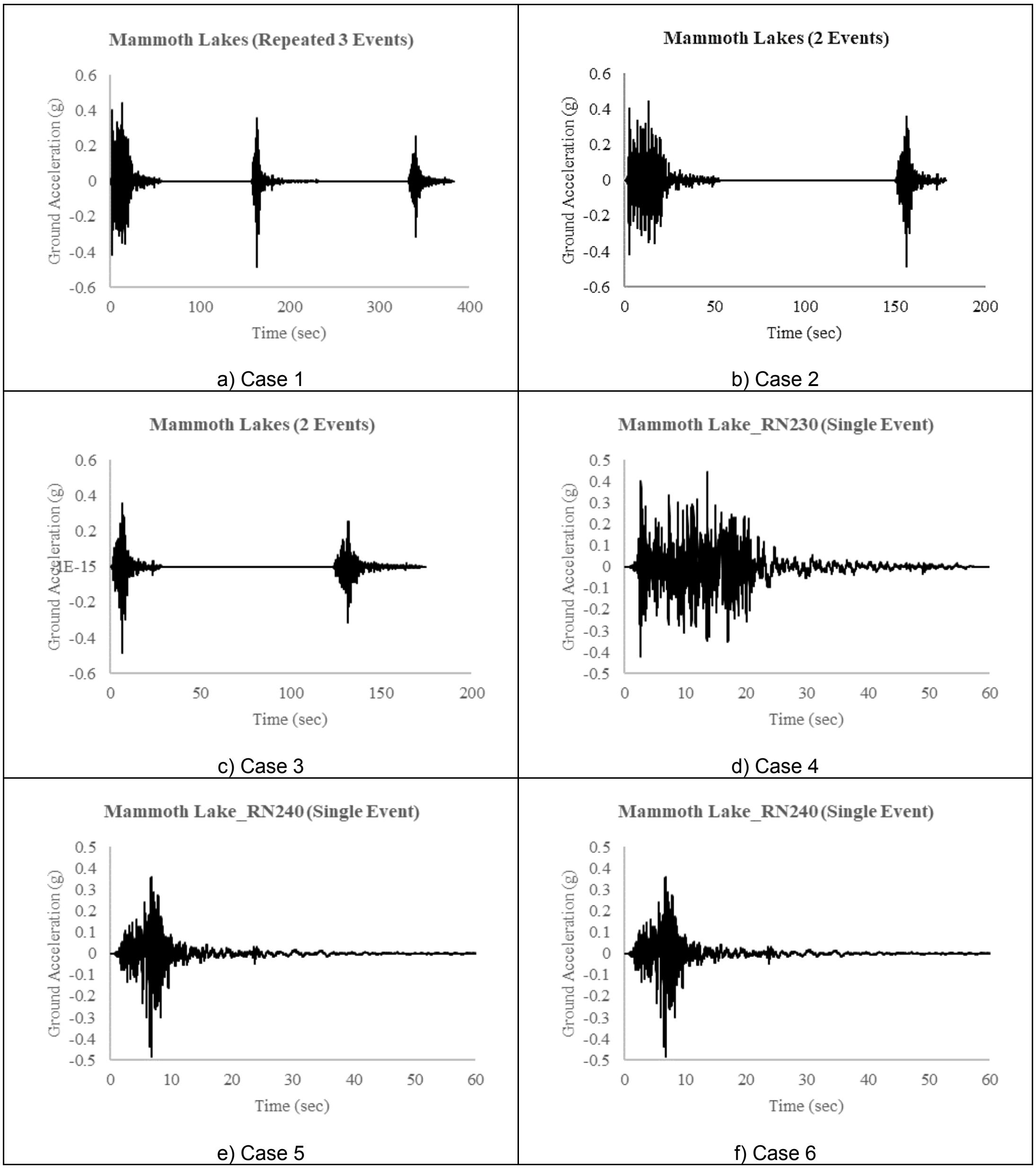

Figure 3. Ground acceleration records

RESULTS AND DISCUSSION

Modal analysis is performed to obtain the dynamic characteristic of the dam body. Table 5 shows the first four natural frequencies of Koyna Dam compared with the results achieved by Chopra and Chakrabarti (Chopra and Chakrabarti, 1973). The comparisons of the results indicate the validity of the present numerical model.

An exponential degradation function d_m is defined in Eq. (6) to determine the mechanical porosity (ϕ_m). The degradation index is evaluated using a compressive strength gain curve, as proposed by Washa et al. (1989). The material parameters used to consider the deterioration effect of concrete material are taken as $\alpha_m = 0.9$, $\beta_m = 1000$, $\phi_0 = 0.02$, and $K_0 = 0.00011$ (Kuhl et al., 2004a). The value of $\phi_c = 0.2$ in the presence of chemical degradation and in the upstream face is considered zero, assuming the absence of silt. The maximum allowable degradation caused by mechanically induced porosity α_s can be assigned between 100% and 0% degradation considering that porosity developed in the concrete at the end of its design life. In this study, the value of α_s for a design life of 100 years is taken in the range of 0.4–1.0. The variation in elastic modulus of concrete with time, with a design life of 100 years, is compared with the different α_s values shown in Figure 5. The results from the plot indicate that concrete will become a pile of sand, which is arguably incorrect at the age of 100 years. The degradation value to consider because of mechanically induced porosity α_s is considered as 0.5 in this study.

Table 3. Seismic sequences

No	Seismic	Date	Category	Magnitude (M)	PGA-H (g)
1	Chalfant Valley	20 July 1986 21 July 1986	Far field	5.8 6.1	0.285 0.447
2	Chi-Chi Taiwan	20 Sept 1999 20 Sept 1999		6.2 6.2	0.223 0.205
3	Chuetsu-Oki Japan	16 July 2007 16 July 2007		6.8 6.8	0.185 0.152
4	Iwate Japan	13 June 2008 13 June 2008 13 June 2008		6.9 6.9 6.9	0.190 0.243 0.154
5	Mammoth Lakes	25 May 1980 25 May 1980 27 May 1980		6.1 5.7 5.9	0.442 0.485 0.315
6	Morgan Hill	24 April 1984 24 April 1984		6.2 6.2	0.585 0.403
7	Whittier Narrow	1 Oct 1987 1 Oct 1987 1 Oct 1987		6.0 6.0 6.0	0.245 0.247 0.194
8	Northridge	17 Jan 1994 17 Jan 1994		6.7 6.7	0.185 0.221
9	Tottori Japan	6 Oct 2000 6 Oct 2000 6 Oct 2000		6.6 6.6 6.6	0.252 0.274 0.231

Table 4. Load combinations

Loads	Combination
EX1	Dead load + Water loads + Case 1
EX2	Dead load + Water loads + Case 2
EX3	Dead load + Water loads + Case 3
EX4	Dead load + Water loads + Case 4
EX5	Dead load + Water loads + Case 5
EX6	Dead load + Water loads + Case 6

Table 5. Natural frequency of Koyna

	Natural frequency (rad/sec)		
Mode	**Present**	**Chopra and Chakrabarti**	**% of deviation**
1	19.93	19.27	3.31
2	50.87	51.50	−1.24
3	69.46	70.56	−1.58
4	96.71	99.73	−3.12

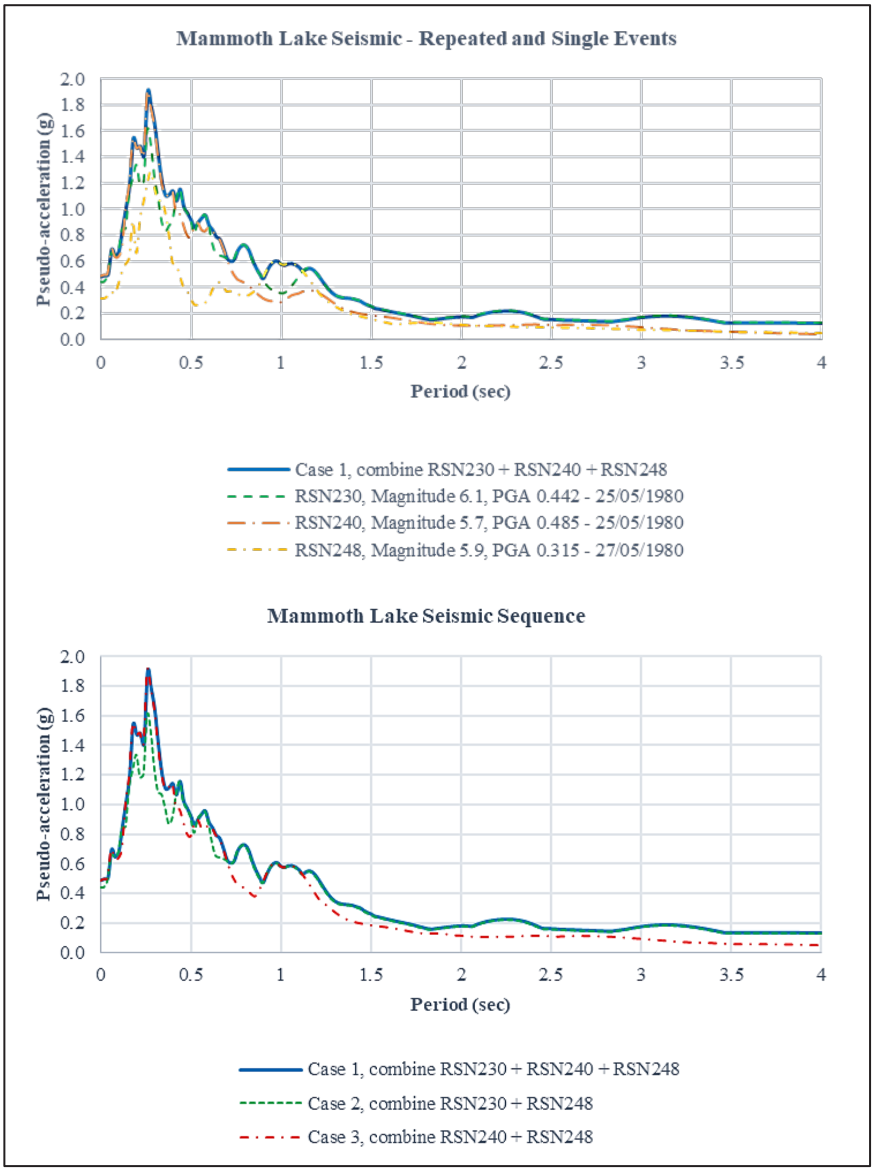

Figure 4. Response spectra of seismic sequences

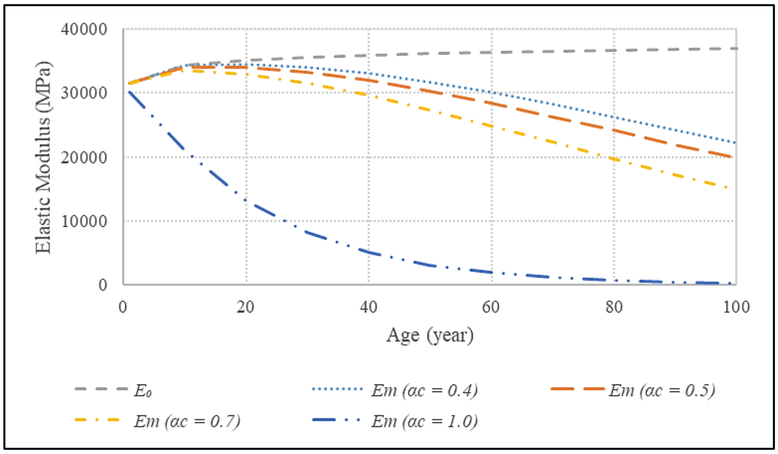

Figure 5. Variation in the elastic modulus of concrete with age

The displacement results are described in Table 6 for Koyna Dam, Model 1, and Model 2 with different concrete strengths and earthquake loadings. Loads EX1 and EX2 show the same displacement values. The results prove that the repeated earthquake is enough to consider only two events. The displacement increases compared with EX1 and EX5 by approximately 0.2% for Koyna Dam, 0.6% for Model 1, and 2.7% for Model 2. The displacement significantly increases with an increase in concrete age. The results imply that the dam performance will be affected after considering the changing concrete strength caused by mechanically induced porosity. The time history of the displacement for Model 1 with different load cases and concrete ages is presented in Figures 6 to 8. The time history pattern shows that for the 100-year concrete dam, the loads of Cases 1, 2, and 3 have higher displacement than that of single earthquake events.

By considering the concrete strength affected by mechanically induced porosity with the repeated earthquake loadings in the models, we plot the results of pseudo-acceleration with 5% damping at the top of the Model 1 dam in Figure 9. The pattern of pseudo acceleration with different combinations of loadings is dissimilar from the first-year concrete strength. However, the value of maximum pseudo-acceleration is the same for Cases 1 and 4, which is 19 m/s². The PSA value for Case 5 is 9.29 m/s², and that for Case 6 is 7.10 m/s² lower than those of Cases 1 and 4. When the concrete age increases to 50 and 100 years, the pseudo-acceleration under Case 1 increases to 21.75 and 22.21 m/s² respectively.

Table 6. Displacement results for Mammoth Lake under single and repeated earthquakes

Loads	Koyna			Model 1 (50 m)			Model 2 (30 m)		
	Year								
	1st	60th	100th	1st	60th	100th	1st	60th	100th
EX1	0.7583	0.8402	1.2037	0.0943	0.1047	0.1493	0.0183	0.0199	0.0287
EX2	0.7583	0.8392	1.2034	0.0943	0.1047	0.1493	0.0174	0.0199	0.0286
EX3	0.7568	0.8389	1.2031	0.0941	0.1037	0.1468	0.0176	0.0200	0.0283
EX4	0.7580	0.8392	1.2034	0.0941	0.1044	0.1491	0.0182	0.0198	0.0284
EX5	0.7567	0.8383	1.2027	0.0937	0.1037	0.1486	0.0178	0.0196	0.0283
EX6	0.7567	0.8387	1.2025	0.0934	0.1035	0.1487	0.0179	0.0200	0.0284

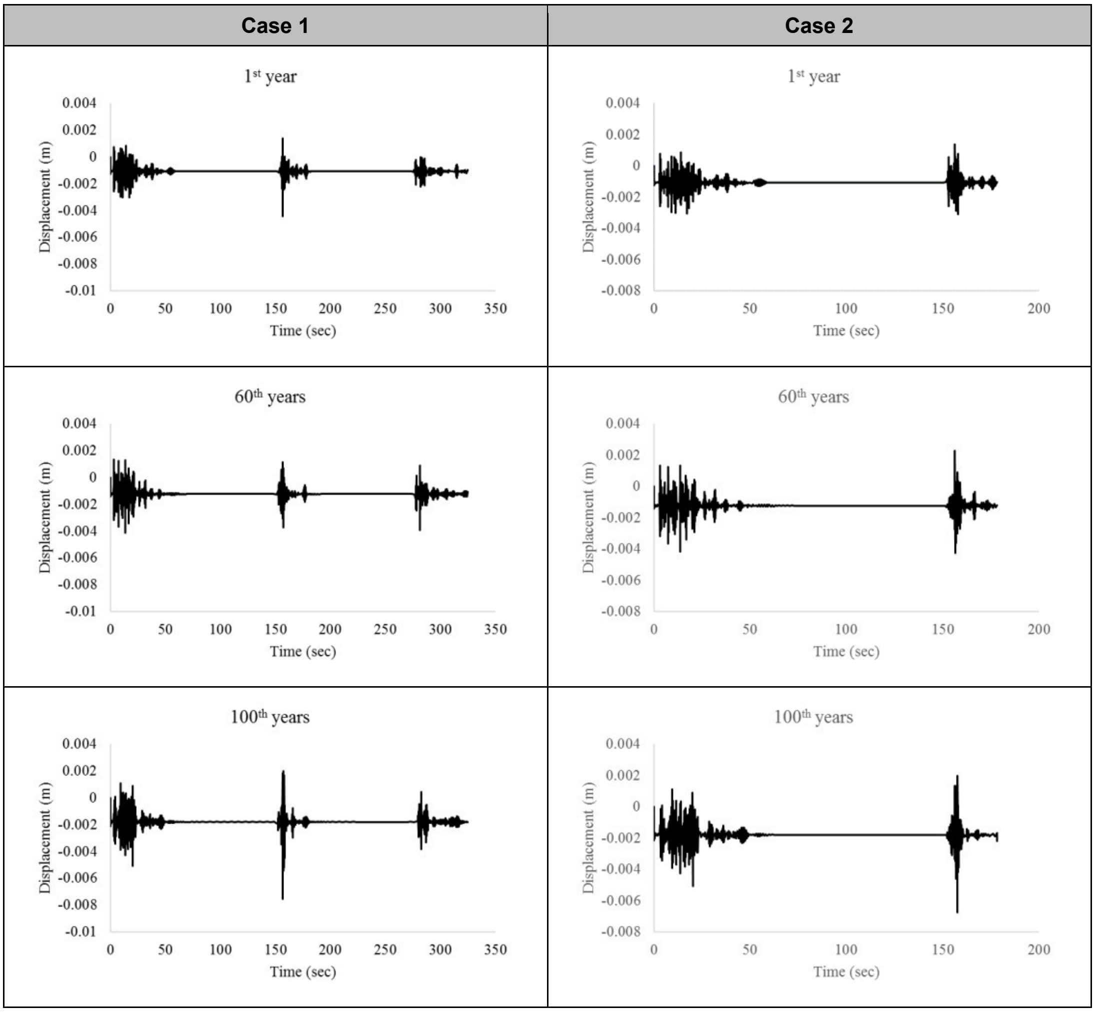

Figure 6. Displacement of Model 1 for loads of Cases 1 and 2

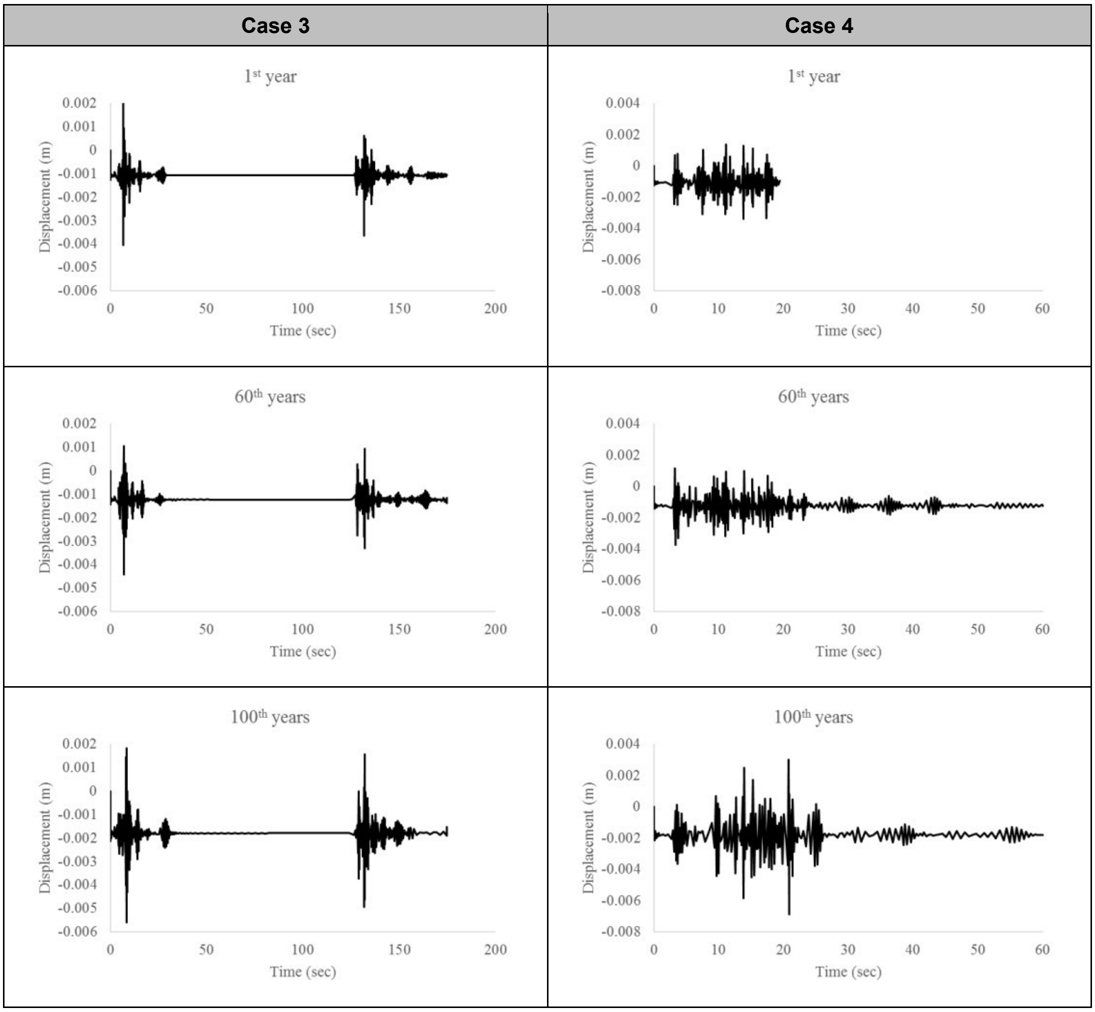

Figure 7. Displacement of Model 1 for loads of Cases 3 and 4

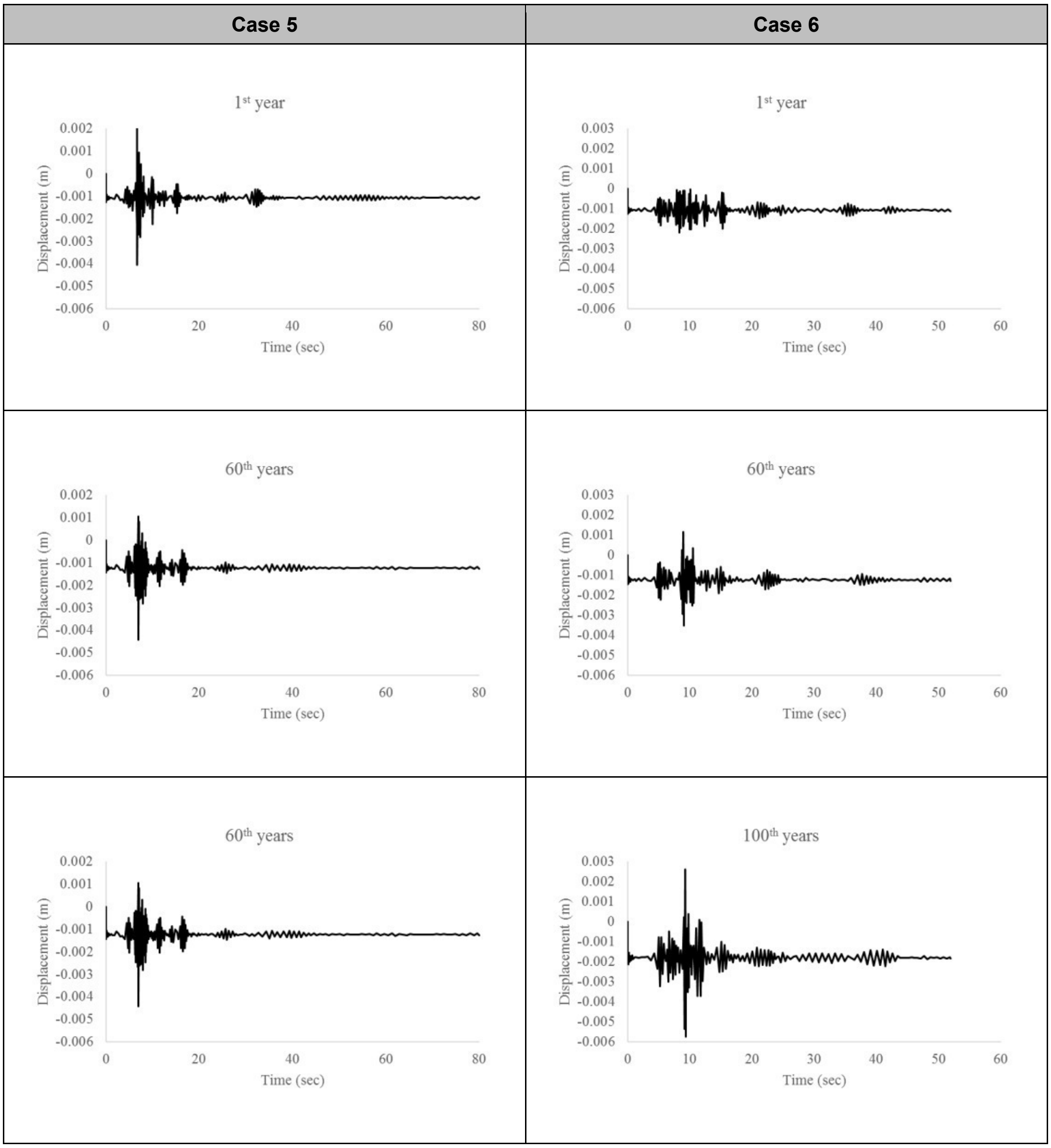

Figure 8. Displacement of Model 1 for loads of Cases 5 and 6

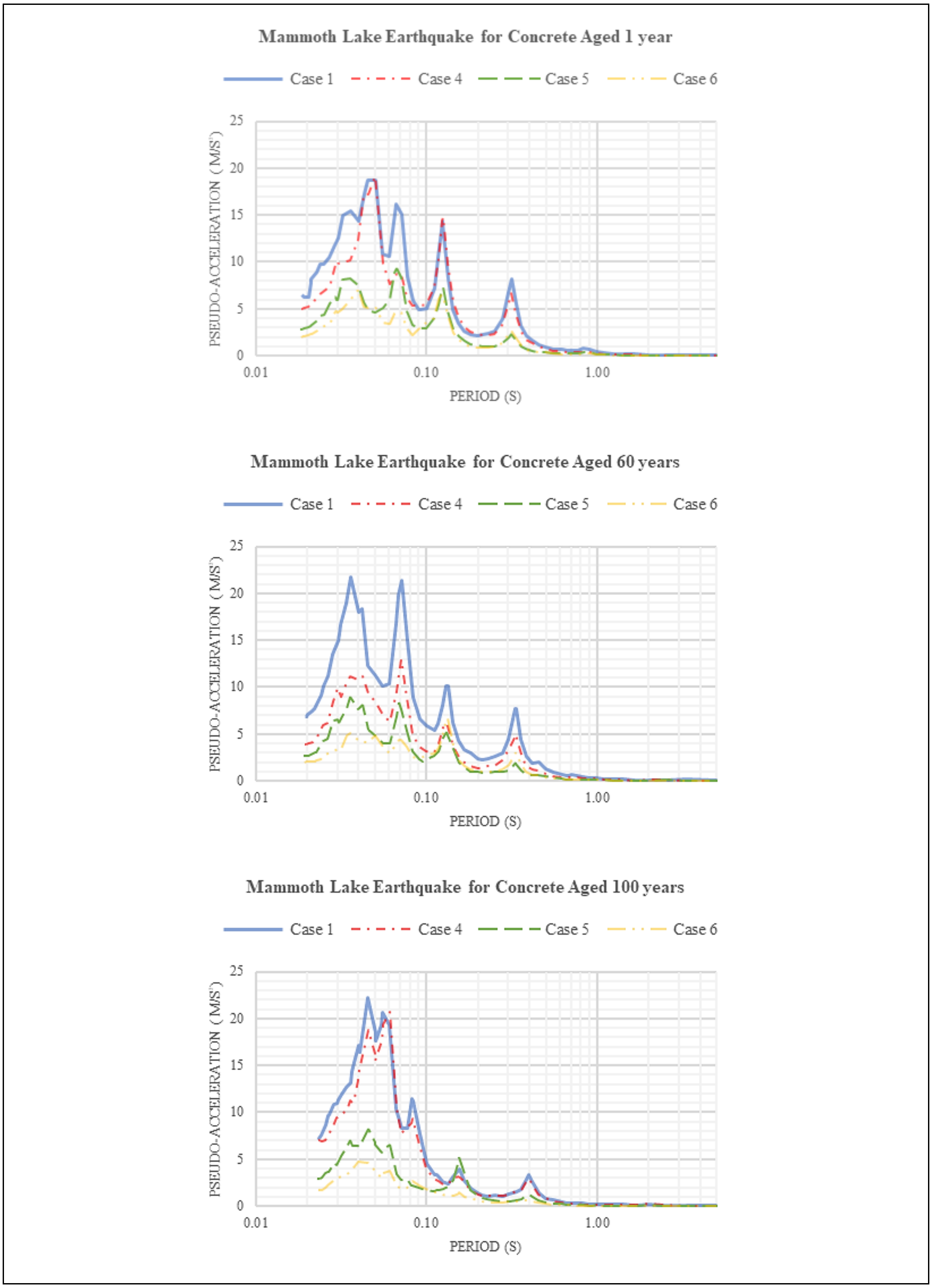

Figure 9. Pseudo-acceleration at the top of Model 1 dam with different concrete ages and load combinations

CONCLUSIONS

This study investigates the performance of aged concrete dams under repeated earthquakes. Three types of dam models with different dimensions are investigated. A detailed study of the problems leads to the following conclusions:

1. The degradation process of concrete reliant on the design life of the structure. The degradation slows down when a high design life is considered. The gain in concrete strength takes place from 1 year to 10 years. However, concrete strength starts decreasing after 10 years old because of environmental factors, which are the chemical and mechanical reactions on concrete. These factors should be considered in the design life of a concrete dam.
2. The response spectra of the ground motion for Case 1 for triple earthquake events and Case 3 for two earthquake events show higher values than those of the other cases. However, the maximum value of response spectrum for Case 1 and Case 3 are similar. It is shown that by considering only two earthquake events for repeated earthquakes is adequate for dam analysis.
3. The highest dam displacement in this study is EX1, which is the combination load with three events of earthquake loadings. The difference in dams between repeated events and a single event is approximately 0.2%–3% in the first-year concrete age. The time history pattern under repeated earthquake also presents a high value of displacement. Owing to the seismic sequence effect to the dam, the repeated earthquake phenomena cannot be ignored.
4. The dam performance under repeated earthquakes increases pseudo-acceleration by approximately 15% compared with the 1-year and 50-year concrete ages. When considering the concrete age of 100 years, the pseudo-acceleration increases to 17%. Concrete degradation caused by chemical and mechanical effects on the concrete should be considered in designing dams because the structural impact would be different.

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ASSESSMENT OF EXHIBITED TEAM ROLES OF CONSTRUCTION TEAM MEMBERS IN SELECTED HIGHER INSTITUTIONS' PROJECTS IN A DEVELOPING ECONOMY

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Abstract
Clients in the Nigerian construction industry often put teams together to achieve project realization (traditional team composition method based on knowledge skills and abilities) without recur to personality and interaction between team members. The performance of the team depends on the personality and interaction of the team members as well as on the expertise and experience of individual team member. The purpose of this study is to assess the exhibited team role of construction team members in selected higher institutions in Nigeria with a view to improving construction project delivery through the selection and composition of appropriate team members. Purposive sampling technique was used to select required higher institutions in the study area. A total of 191 questionnaires were distributed to obtain information from construction team members who participated in the selected construction projects in the institutions. An instrument for measuring team roles of construction team on construction projects was synthesised. Mean Item Score (MIS) was used for data analysis. The finding of this research indicate that the dominant team role exhibited by Quantity Surveyors, Architects, Structural/ Civil Engineers, Service Engineers, Clients and Contractors is Resource investigator, Chairman/Coordinator, Completer, Chairman/Coordinator, Chairman/Coordinator and Monitor/Evaluator respectively. The predominant team role exhibited by construction team members is Coordinator/Chairman because (3 of the 6 studied construction team members demonstrated Coordinator as their dominant team role). The study concluded that a deliberate attempt should be made in determining the exhibited team roles of construction team members before co-opting them into a team so as to improve construction projects delivery.

Keyword: *Team roles, Team members, higher institutions, project success, construction project*

INTRODUCTION

Construction projects have always been a very important part of human civilization. The construction industry is experiencing a growing numbers of construction projects of complex nature which resulted from the rapid technological development of the last century (Ogunlana et al., 2001). Teams combine the efforts of individual contributors and provide synergistic outcomes. This unique process, although not fully understood as noted by (Kozlowski and Klein, 2000), has led organisations to rely frequently on teams as prime movers for innovation and change. The execution of construction projects is based on application of team work from ages. The management of construction projects has been carried out since man first cooperated to erect buildings, yet there is little documented knowledge of how people interact in this process. It is revealing that historical and contemporary accounts of construction work pay little attention to how people work together and manage their activities.

Several researches have defined the term construction project team in various ways. According to Chan and Tam (2001), a project team in the construction industry is a group of construction professionals and personnel from one or more organizations who combine to fulfill the necessary design, detailing and construction functions comprising the construction project. Winch (2002) further defined this team as the consultants, contractors, specialists and others who come together to design, manage and construct a product. When construction teams are evaluated with regard to the ideal team definition given by Katzanbach and Smith (1993), there are many features that suggest that construction teams are similar to the ideal teams. The construction team is comprised of a relatively small number of key people made up of a diverse range of professionals, each with expertise in their respective disciplines. Therefore, it is obvious that each member possesses complementary skills even though each participating firm has its own ongoing business objectives; they also have a common project objective, which is a key feature in an ideal team. The reasons given above suggest that the construction team is similar to the ideal team, the lack of mutual accountability and the existence of contrasting objectives as noted by Cornick and Mather (1999) can cause construction teams to deviate from the ideal team definition. Team performance is such an important ingredient of success in every project. Teams are used in organisations in most sectors and industries due to the recognition that they are able to outperform individuals acting alone, especially when performance requires multiple skills and judgments (Hayes, 2002; Scarnati, 2001).

The exhibited team roles of construction stakeholders is a major determinant of the performance of such team as improper construction team composition could hinder construction projects optimum performance. Literature abound that have examined the team application in construction industry (Anyanwu, 2013; Bernard and Andrew, 2011; Carson and Isaac, 2005; Senaratne and Gunawardene, 2015; Stewart et al., 2005) but no known study have attempted to examine the exhibited team roles of construction team members especially as it affect higher institutions projects. Khan and Hussain (2016) and Anyanwu (2013) examined the functional roles of construction team members while the current study examined the team roles of construction team members. Construction team members functional role refers to the job demands that a person has been engaged to meet by supplying the requisite technical skills and operational knowledge (Senaratne and Gunawardene, 2015) whereas team role refers to a tendency to behave, contribute and interrelate with others at work in certain distinctive ways (Belbin, 1993).

In view of the foregoing, this paper therefore, assesses the exhibited team roles of construction team members in selected higher institutions with a view to improving construction projects delivery in Nigeria. The findings of this study will be of immense use to the construction practitioners and stakeholders in that it will reveal the exhibited team roles of construction team members rather than the functional roles that previous researchers have unraveled. It will also be useful for project managers in the selection of their team members in quest for delivery of projects to the required standard and satisfaction of the clients.

LITERATURE REVIEW

The complex nature and the presence of different skills in construction, means that teams are essential and needed for success in construction (Bower, 2003; Gould, 2002). Construction Excellence (2004) concluded that this is because they enable complimentary use of available skills to achieve high productivity. The success of a construction project depends on a number of factors, such as contractual arrangements, project complexity, competency of project managers, relationships between project participants and the abilities of key project members, etc. (Mohsini, and Davidson, 1992; Chua et al., 1999). However, Sai et al. (2004) opined that successful project delivery requires the concerted effort of the project team to carry out the various project activities. In response to performance improvement demands on the construction industry, research into teams has significantly increased over the last two decades (Constructing Excellence, 2004; Ochieng and Price, 2009; Smith and Offodile, 2008). Many of the studies have adapted factors that influence improved performance in the manufacturing sector. The results of such research have demonstrated that team have significant potential for increasing productivity (Hayes, 2002) and frequently result in considerable performance improvement (Bernard and Andrew, 2011). This is largely because they can get better results than where individuals operate within defined job roles. Within a team, there tends to be a variety of knowledge and skills, which can be pooled along with information and resources that can be shared (Driskell, 1992).

Pinto (2007) posited that project success depends as much on the effective management of project personnel as on technical management. Interest on how project management practices can be improved to create conditions for project success is high for both practitioners and researchers (Kieser and Nicolai, 2005; Lingham et al., 2006). Christina and Danny (2009) commented that for construction projects, team design and leadership factors are the most important factor in teams. Team design refers to the composition of the team and the functional backgrounds, skills and expertise of team members. Leadership of the team refers to the project leader's skills, experience and expertise and also to their continuity and the incentives provided. Dickinson and McIntyre (1997) identified and defined seven key components of teamwork which are critical to any improvement exercise: communication; team orientation; team leadership; monitoring; feedback; backup behaviour; and co-ordination.

Clients in the construction industry often put teams together to achieve project realization (traditional team composition method based on knowledge skills and abilities). The performance of the team depends on the personality and interaction of the team members and on the expertise and experience of each individual. It is much like casting actors for a play, each actor brings a certain quality and dimension and unless the casting is done with care, the director will find the cast incompatible with the script (Wiggins, 1985). The same is true in teams, unless the team is selected with care; the output from the team is unlikely to meet the client expectations. Quite often, companies wonder why their teams are ineffective and not delivering to time, quality and cost which can be put down to team composition and interaction. Team building is not just about putting together human resources and then deploying them on a project. It is the creation of a winning and collaborative spirit among team members so that they can work efficiently and in harmony with each other to achieve project goals. However, Lewis (1998) asserted that team building process is probably the most neglected aspect of project management.

Belbin (1981) as well as Belbin (1993) opined that optimal team performance may be obtained when each of the nine team role behaviours can be provided by the members of the team (the team type which emerged through a process of observation and reflection). Members of a balanced and complete team should possess the following:

Chairman or Co-ordinator: Coordinators are confident, stable and mature and because they recognize abilities in others, they are very good at delegating tasks to the right person for the job (Belbin, 1981). A coordinator often becomes the default chairperson of a team, stepping back to see the big picture. The Coordinator clarifies decisions, helping everyone else focus on their tasks. The coordinator is someone tolerant enough always to listen to others, but strong enough to reject their advice. According to Belbin (2013), such a person is mature, confident, identified talents, clarifies goal and delegate effectively.

An Implementer or Company worker: Fisher et al. (1998) asserted that the company worker or implementer is described as; conservative, controlled, disciplined, efficient, inflexible, methodical sincere, stable, and systematic. The Implementer takes what the other roles have suggested or asked, and turns their ideas into positive action. They are efficient and self-disciplined, and can always be relied on to deliver on time. They are motivated by their loyalty to the team or company, which means that they will often take on jobs everyone else, avoids or dislikes. He is responsible for implementing acceptable plans effectively and systematically. He is not only the 'arranger' but also a worker on behalf of the organisation rather than his behalf. He is positively selfish, tough-minded, practical, discipline, traditional, faithful and tolerant (Hassan, 2008).

A completer or finisher: The completer is a perfectionist and will often go the extra mile to make sure everything is "just right," and the things he or she delivers can be trusted to have been double-checked and then checked again. Martin and Eleftheria (2006) posited that completer is painstaking, conscientious, anxious, searches out errors and omissions, delivers on time, perfectionist and obsessional. The completer/ finisher has a strong inward sense of the need for accuracy, rarely needing any encouragement from others because that individual's own high standards are what he or she tries to live up to. They may frustrate their teammates by worrying excessively about minor details and refusing to delegate tasks that they do not trust anyone else to perform.

A Monitor or Evaluator: monitor or evaluators are fair and logical observers and judges of what is going on. They are good at detaching themselves from bias and as a result, they are often the ones to see all available options with the greatest clarity. They take everything into account, and by moving slowly and analytically, will almost always come to the right decision (Martin and Eleftheria, 2006). Belbin (1981) posited that the monitor/ evaluator is not deflected by emotional arguments, is serious minded, tends to be slow in coming to a decision because of a need to think things over. He takes pride in never being wrong and lacks drive and ability to inspire others. He may appear dry and boring or even over-critical. Sober, strategic and discerning. He sees all options and judges accurately (Eric, 2007).

A plant or Planter: Plants are creative, unorthodox and a generator of ideas. If an innovative solution to a problem is needed, a Plant is a good person to ask. According to Belbin (1993), a good plant will be bright and free-thinking. Plants can tend to ignore incidentals and refrain from getting bogged down in detail.

A Resource investigator: The resource investigator is someone who explores opportunities and develops contacts. Resource investigators are good negotiators who probe others for information and support and pick up other's ideas and develop them. The Resource Investigator gives a team a rush of enthusiasm at the start of the project by vigorously pursuing contacts and opportunities. He or she is focused outside the team, and has a finger firmly on the pulse of the outside world.

Hassan (2008) asserted that resource investigator is determinant, dominant and extroverted. He is the second member to be innovative. They mostly resemble plant except for the personal affair and original ideas. Despite the resemblance with the plant on developing unique ideas, the main difference is resource investigator's being extroverted (preference to interact with the environment).

A shaper: Belbin (2004) commented that the shaper is challenging, dynamic, thrives on pressure. He possesses drive and courage to overcome obstacles. The shaper is a task-focused leader who abounds in nervous energy, who has a high motivation to achieve and for whom winning is the name of the game. The shaper is committed to achieving ends and will 'shape' others into achieving the aims of the team. He or she will challenge, argue or disagree and will display aggression in the pursuit of goal achievement. Two or three shapers in a group can lead to conflict, aggravation and in-fighting.

A specialist: Fisher et al. (1998) described specialists as passionate about learning in their own particular field. As a result, they will have the greatest depth of knowledge, and enjoy imparting it to others. They are constantly improving their wisdom. If there is anything they do not know the answer to, they will happily go and find it. Specialists bring a high level of concentration, ability, and skill in their discipline to the team, but can only contribute on that narrow front and will tend to be uninterested in anything which lies outside its narrow confines. The specialist's strength lies in being a dedicated and focused individual who likes to learn and constantly build his or her knowledge (Belbin, 1993). He brings dedication, single-minded, self-starting as well as provides knowledge and skills in rare supply. They are often highly introverted and anxious and tend to be self-starting, dedicated, committed, contributing only on a narrow front and dwells on technicalities.

A Team worker: team worker is co-operative, mild, perceptive, diplomatic builds and averts friction, calms the waters; indecisive on; listens, crucial issues; avoids situations that may entail pressure (Martin and Eleftheria, 2006). According to Belbin (1981), a team worker is the greasy oil between the cogs that keeps the machine that is the team running. They are good listeners and diplomats, talented at smoothing over conflicts and helping parties understand each other without becoming confrontational.

The Belbin Team Role Self-Perception Inventory (BTRSPI) was designed to measure behavioural characteristics which individuals display when working in teams (Lessem and Baruch, 1998). Most personality traits are acknowledged to be fairly constant, behaviour can change more readily, adapting to changes in any of those factors which influence it and as a result, team role preferences might change over time (Belbin, 1981). Whilst it is unlikely that an individual's profile will change dramatically or be reversed altogether, some alterations are expected, in line with a change of job role or work environment, or as a result of a major life change. An individual does not have one Team Role, but a combination of dominant, manageable and least dominant roles. The distribution and interrelation of these roles across an individual's profile have a great influence on the way the roles will be played out in practice and experienced by others.

The exhibited team roles of an individual's team members are analysed in three categories: Dominant Roles are those roles which an individual is comfortable playing and which come naturally. Manageable Roles are those roles which an individual can play if required for the benefit of the team. These may be cultivated to broaden the individual's team working experience. And least dominant Roles are those roles which the individual does not naturally or comfortably assume. It is generally recommended that the individual avoids contributing in these areas, lest the pitfalls of the behaviour outweigh the strengths.

METHODOLOGY

The research population consisted of team members on construction projects which included Clients, Contractors, Architects, Quantity Surveyors, Structural Engineers and Services Engineers, that participated in the 35 selected completed public educational construction projects. A visit to the selected case study institutions (Obafemi Awolwo University (OAU), Ile Ife and Federal Polytechnic, Ede (FPE) revealed that OAU and FPE executed 27 and 57 construction projects within the period (with and without consultants) respectively. However, 10 and 25 construction projects were with complete number of consultants respectively. Therefore, the total number of projects studied was 35 completed construction projects. List of the team members that participated in the selected projects were obtained from the Physical Planning and Development Unit of the selected institutions. The population for the questionnaire administration included all team members that participated in the selected completed construction projects. The two institutions were selected because they were the only ones owned by the federal government in the study area and because the researchers have working relationship with the institutions thereby made access to data easier.

The sample size for this study were the whole 35 sampled completed construction projects teams with 191 respondents, that is, 35 Clients, 35 Contractors, 31 Architects, 30 Civil Engineers, 25 Services Engineers and 35 Quantity Surveyors as indicated in Table 1. The population size for Architects, Structural/ Civil engineers and Service engineers were not up to 35 because some of the selected construction projects were civil engineering projects.

Table 1. Population size of each respondent

S/N	Respondent	Population
A	Clients	35
B	Contractors	35
C	Consultants	
	Architects	31
	Quantity Surveyors	35
	Civil/Structural Engineer	30
	Service Engineers	25
	Total	191

Source: Physical Planning Development Unit, Federal Polytechnic Ede and Physical Planning Development Unit Obafemi Awolowo University, Ile Ife. 2013.

To measure the roles exhibited by team members on construction projects, a team role measuring instrument was synthesized. Three statements were formulated based on the core traits of each team roles agreed to by many scholars that have worked in this area. These statements were mixed in such a way that the respondent did not know which statement is for a specific team role, the respondents were asked to rate themselves on a 5-point Likert scale on each statement where the respondent has highest scores was his exhibited team role. Table 2 shows the statements and the corresponding team role. In analysing exhibited team roles of construction team members, 3.50 was taken as the minimum mean score as basis for accepting that a team role was exhibited (this is premise on the fact that in the Likert scale used for this study, 3 is neutral and 4 is agreed; therefore, the average score of 3.5 is a good basis). Where a team member played multiple roles, the first three roles he played with highest scores would be his dominant roles, the next three would be manageable roles and the last three would be his least dominant roles. Data were collected by mean of a structured questionnaire designed and distributed to the 191 respondents that participated in the 35 selected completed construction projects from the two selected institutions. Out of 191 questionnaires administered, 144 filled and returned. However, only 100 of this were used for analysis; this was because the responses of the team members were not complete for the remaining 44 and not fit for analysis because the study was team based. This represents 75 percent response rate. This responses rate was considered sufficient for the study considering the assertion of Oke and Ogunsemi (2009) that the result of a survey could be considered as biased and of little significant if the return rate was lower than 20-30%.

Table 2. Team roles measuring instrument for construction team members

	STATEMENT	CORRESPONDING TEAM ROLES
1	I am always anxious to achieve goals	
2	I always exercise self control every time	Completer/Finisher
3	I am self disciplined always	
4	I am a good extrovert	
5	I am always positive in my thinking	Chairman/Coordinator
6	I can be trusted always	
7	I am always methodical in my approach	
8	I may be inflexible a times	Company worker/Implementer
9	I am always conservative in my relationship	
10	I am open to change always	
11	I am fair minded in my dealings	Monitor/Evaluator
12	I am always stable	
13	I love to be dominant always	
14	I am always original in my thinking	Planter
15	I like to be radically minded always	
16	I am always optimistic in my thinking	
17	I am always diplomatic in my decision	Resource investigator
18	I am always Inquisitive	
19	I am often emotional in my reaction	
20	I am always self confident	Shaper
21	I could be impatient a times	
22	I am always Unassertive	
23	I am always loyal to my team mates	Team worker
24	I am always supportive to my team mates	
25	I am passionate about learning	
26	I bring a level of concentration to all I do	Specialist
27	I am single-minded always	

Source: Adapted from Belbin (1993); Fisher et al. (1998) and Martin and Eleftheria (2006)

Table 3. Summary of characteristics of questionnaire respondents

Category	Classification	Frequency	Percent
Role played	Quantity Surveyor	17	17.0
	Architect	16	16.0
	Civil/structural Engineer	17	17.0
	Services Engineer	16	16.0
	Client	17	17.0
	Contractor	17	17.0
	Total	100	100.0
Years of experience	0-5	7	7.0
	6-10	17	17.0
	11-15	39	39.0
	16-20	11	11.0
	21-30	24	24.0
	Above 30	2	2.0
	Mean	**15**	100.0
Academic qualification	HND	9	9.0
	PGD	26	26.0
	Bachelor	22	22.0
	Masters	41	41.0
	PH.D	2	2.0
	Total	100	100.0
Membership of professional bodies:	NIQS	22	23.0
	NIA	23	23.0
	NIOB	9	9.0
	NSE	40	40.0
	Others	2	5.0
	Total	96	100.0
Type of Memberships	Graduate	15	16.0
	Associate	78	81.0
	Fellow	1	1.0
	Others	2	2.0
	Total	96	100.0
Number of projects executed	1-10	14	14.0
	11-20	18	18.0
	21-30	34	34.0
	31-40	9	9.0
	41-50	7	7.0
	ABOVE 50	18	18.0
	Mean	**29**	100.0

Source: Field survey (2013)

DATA PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

Characteristics of respondents to the questionnaire

Table 3 shows the general characteristics of respondents. It was observed that quantity surveyors, structural/civil engineers, clients and contractors represent 17% each of the respondents, while architects and services engineers represents 16% each. The average year of working experience of the respondents was calculated to be 15years which is adequate for the study because information supplied by this category of professionals is considered adequate and reliable for analysis. It could be observed that majority of the respondents are Masters holder with 41%. 96% of the respondents were members of different professional bodies. This was expected because a client may not necessarily be a member of any professional body. Majority of these professionals are corporate (associate) members which represents 78%. The average number of project handle or executed by the respondents was calculated to be 29 and this was considered appropriate as the respondents had sufficient experience.

Exhibited Team Roles of Construction Team Members

Respondents were asked to assess themselves on a number of questions developed based on the core traits of each team role. The results as presented in table 4 shows that for Quantity Surveyors; the dominant exhibited team roles were resource investigator, team worker and coordinator while the manageable exhibited team roles were specialist, monitor/ evaluator and completer. For Architects, the dominant exhibited team roles were chairman/ coordinator, specialist and completer while the manageable exhibited team role were planter, monitor/ evaluator and company worker/ implementer, the least dominant exhibited team roles were team worker and resource investigator. For Structural/ Civil engineers; the dominant exhibited teams roles were completer, specialist and resource investigator, the manageable exhibited team roles were chairman/ coordinator, monitor/ evaluator and team worker and the least dominant exhibited team roles were planter, company worker/ implementer and shaper.

For Service engineers, dominant exhibited team roles were chairman/ coordinator, specialist and resource investigator while the manageable exhibited team roles were monitor/evaluator, team worker and company worker/ implementer and the least dominant exhibited team role were shaper, planter and completer. For Clients, the dominant exhibited team role were chairman/ coordinator, specialist and completer while the manageable team roles were resource investigator, monitor/ evaluator and team worker and the least dominant exhibited team roles were company worker/ implementer, planter and shaper. And for Contractors, the dominant exhibited team role were monitor/ evaluator, team worker and completer whereas the manageable exhibited team roles were resource investigator, planter and chairman/ coordinator and the least dominant exhibited team roles were specialist and shaper.

The exhibited team roles of construction team members are a combination of the different team roles at various levels. The exhibited team roles of construction team members were analysed as dominant team roles, manageable team roles and least dominant team roles. The finding of this research indicate that the dominant team role exhibited by

Quantity Surveyors, Architects, Structural/ Civil Engineers, Service Engineers, Clients and Contractors are Resource investigator, Chairman/ coordinator, Completer, Chairman/ coordinator, Chairman/ coordinator, and Monitor/ Evaluator respectively and that the predominant team role exhibited by construction team members is coordinator/ chairman (50% of construction team member studied exhibited coordinator as their dominant team role). This study further reveal that team members exhibited more than one team role and there may be problem in specializing in a particular area as this alluded to the finding of Arroba and Wedgewood-Oppenheim (1994) and Senaratne and Gunawardene (2015) that all the design team members studied showed different preferences for different team roles and had taken up more than one (two to four) team roles besides their functional roles. The main implication of the finding of this study to the construction industry is that the construction team members are able to perform any team role within their exhibited team roles as situation demands but will perform optimally at the most dominant exhibited team role. This finding is essential to construction projects managers to ascertain the exhibited team roles of their team members at the inception of construction project to achieve optimal performance

Table 4. Exhibited team roles of construction team members

TEAM ROLES	QSV		ARC		STE		SRE		CLI		CON	
	Mean	Mean Avg.	Mean	Mean Avg.	Mean	Mean avg.	Mean	Mean Avg.	Mean	Mean Avg.	Mean	Mean Avg.
Completer/finisher		**4.02**		**4.08**		**4.18**		**3.56**		**4.22**		**3.84**
I am always anxious to achieve goals	3.53		3.56		3.41		2.88		3.29		3.71	
I always exercise self control every time	4.18		4.19		4.41		3.81		4.65		3.88	
I am self disciplined	4.35		4.50		4.71		4.00		4.71		3.94	
Chairman/Coordinator		**4.20**		**4.58**		**4.04**		**4.42**		**4.37**		**3.55**
I am a good extrovert	3.65		4.31		3.76		4.31		4.00		3.41	
I am always positive in my thinking	4.59		4.69		4.18		4.44		4.47		3.71	
I can be trusted always	4.35		4.75		4.18		4.50		4.65		3.53	
Company worker/Implementer		**3.39**		**3.85**		**3.67**		**3.83**		**3.94**		**3.31**
I am always methodical in my approach	3.94		4.19		3.88		4.06		4.35		3.53	
I may be inflexible a times	3.06		3.75		3.65		3.75		3.82		3.12	
I am always conservative in my thinking	3.18		3.63		3.47		3.69		3.65		3.29	
Monitor/Evaluator		**4.10**		**4.02**		**3.88**		**4.02**		**4.02**		**4.04**
I am open to change always	3.94		3.44		3.65		4.13		3.53		4.06	
I am fair minded in my dealings	4.18		4.13		3.94		3.94		4.24		4.18	
I am always stable	4.18		4.50		4.06		4.00		4.29		3.88	
Planter		**3.33**		**4.06**		**3.69**		**3.58**		**3.90**		**3.73**
I love to be dominant always	2.71		4.06		3.29		3.25		3.53		3.24	
I am always original in my thinking	4.24		4.50		4.35		3.75		4.35		4.06	
I like to be radically minded always	3.06		3.63		3.41		3.75		3.82		3.88	

Table 4. Exhibited team roles of construction team members (Cont'd)

TEAM ROLES	QSV Mean	QSV Mean Avg.	ARC Mean	ARC Mean Avg.	STE Mean	STE Mean avg.	SRE Mean	SRE Mean Avg.	CLI Mean	CLI Mean Avg.	CON Mean	CON Mean Avg.
Resource investigator		**4.25**		**3.56**		**4.08**		**4.21**		**4.12**		**3.76**
I am always optimistic in my thinking	4.41		3.81		4.29		4.44		4.29		3.94	
I am always diplomatic in my decision	4.00		3.56		4.06		4.13		4.06		3.76	
I am always Inquisitive	4.35		3.31		3.88		4.06		4.00		3.59	
Shaper		**3.12**		**3.31**		**3.59**		**3.69**		**3.69**		**3.35**
I am often emotional in my reaction	2.35		2.75		3.18		3.31		3.53		3.35	
I am always self-confident	4.18		4.19		4.29		3.94		4.18		3.65	
I could be impatient a times	2.82		3.00		3.29		3.81		3.38		3.06	
Team worker		**4.20**		**3.75**		**3.75**		**3.98**		**3.96**		**3.90**
I am always Unassertive	3.29		2.56		2.71		3.38		2.88		2.88	
I am always loyal to my team mate	4.59		4.13		4.29		4.44		4.59		3.53	
I am always supportive to my team mate	4.71		4.56		4.24		4.13		4.41		5.29	
Specialist		**4.12**		**4.44**		**4.16**		**4.27**		**4.25**		**3.51**
I am passionate about learning	4.59		4.56		4.53		4.31		4.35		3.71	
I bring a level of concentration to all I do	4.29		4.63		4.35		4.50		4.53		3.59	
I am single-minded always	3.47		4.13		3.59		4.00		3.88		3.24	

Key: ARC- Architect; QSV- Quantity Surveyor; STE- Structural/Civil Engineer; SRE- Service Engineer; CLI- Client; CON- Contractor

CONCLUSIONS AND RECOMMENDATIONS

The study examined the exhibited team roles of construction team members of selected projects in higher institutions of learning with a view to understanding the team roles that are peculiar to various construction professionals. The study concluded that the construction team's members (architect, quantity surveyor, services engineer, civil/structural engineer, contractor and client) have more than one exhibited team roles though some were dominant, few were manageable while others were least dominant. This is because in a typical studied construction team, all the nine team roles were played though the team members were between five and six. It was further revealed that the most dominant role exhibited by Quantity Surveyors is Resource investigator, Chairman/coordinator is exhibited by Architects, clients and service engineers, Structural/ Civil Engineers is Completer, while Contractors is Monitor/Evaluator. Overall, the predominant team role exhibited by construction team members is Coordinator/Chairman in that about 50% of the studied construction projects team members are Coordinator/Chairman according to their traits.

Based on the findings of the study on exhibited team roles of construction professionals and in the quest to achieve improved construction delivery the study recommended that; all the team members on a construction project should be studied by the team leader especially the project manager and their exhibited team roles should be determined before co-opting them to be member of a team. Special consideration and attention should be giving to studying architect, service engineer and client before commissioning a construction team as these three members has the same exhibited team roles and if this is allowed to play out it could hinder optimum service delivery of the team. This study has contributed to the body of knowledge by highlighting the exhibited team roles of construction professionals appointed on selected higher institution projects. This will be useful for clients, project managers, construction professionals as well as other stakeholders involved in construction of infrastructure in determining the appropriate mix of professionals that will constitute the right team. Such will be of great help in delivering construction projects not only to traditional delivery indices of time, cost and quality but to the satisfaction of clients and other project stakeholders. Further study can be tailored towards other forms of projects such as residential, corporate building, etc. and effects of the absence of one or more of the identified team roles can also be examined. More so, comparative analysis of team roles exhibited by each group of professionals on different projects and in different environment or circumstances should also be studied for better assessment of the subject area.

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DAMAGE ASSESSMENT BASED ON SENSITIVITY OF MODAL PARAMETER IN PLATED STRUCTURE

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Abstract
Damage assessment of plated structures based on modal parameter is of interest to many researchers and a large number of studies have been conducted in this field. In the lifetime of a structure, performance and stability will degrade due to many factors. This process usually comes with the development of corrosion and loss of thickness in the affected region. This paper describes a study of the vibration characteristics of square and rectangular plate structures undergoing corrosion and loss of section problem. A finite element analysis utilizing Abaqus code has been adapted to model this problem. First, the baseline model of undamaged and healthy plate was modelled to determine its natural frequency and mode shape. The baseline model results were then used to make comparisons with a damage model. The mode shape for each damage scenario was extracted and further evaluated to study the sensitivity of the mode shape toward the presence of damage. The size of damage, position, and depth of loss of thickness vary for different damage cases. Significant reduction of natural frequency and localization of mode shape in the damaged region can be observed in the presence of severe damage in plated structures.

Keywords: *Finite element analysis; Modal analysis; Mode shape; Natural frequency; Plate structure*

INTRODUCTION

Plated structure is part of good load carrying and is an important part of a structure in the construction field. Effective structural integrity evaluation and the detection of structural damage at the earliest possible stage are of interest in many engineering fields. Damage development should be identified at the earliest possible stage to provide fast remediation and ensure the safety and reliability of the structure. Damage assessment based on nondestructive technique utilized more sophisticated instruments such as acoustic emission (Aldahdooh et al., 2012), x-ray (Lyubimova et al., 2017), guided wave (Zima et al., 2016), and high speed video camera (Chen et al., 2015). Each of these techniques has its own specific application together with advantage and limitation. On the other hand, damage detection based on vibration characteristics provides valuable information of the global response of structure to identify the local change in the structure. The presence of structural damage leads to changes in the physical properties of the structure, causing significant change to its modal properties. This includes frequencies, mode shapes, and modal damping (Farrar et al., 1997). Modal analysis of a structure provides information on natural frequency and mode shape. This information is valued in understanding the dynamic behavior of the structure. Using the shift of natural frequencies to detect structural damage was proposed by Lifshitz and Rotem in 1969 (Lifshitz & Rotem, 1969). Since then, extensive research has been conducted utilizing changes in frequencies as a tool to indicating the presence of damage in structures.

Many studies have confirmed that the modal parameters are one of promising indicators for damage identification method in the structure. Modal curvature which is curvature of the mode shape has been utilize by Yang et al. (2017) to detect damage beam structure. Shahsavari et al. (2017) adapted damage detection algorithm to detect anomalies in mode shapes of the beam structure. Further, Qiao et al. (2011) performed a comprehensive review of damage identification based on vibration characteristics of plated structures with the damage identification conducted based on four major categories; natural frequency based, mode shape based, curvature or strain mode shape based, and methods that combine both natural frequency and mode shape for damage identification. Damage identification based on natural frequency provides an advantage when implemented on a real structure, as natural frequency may be obtained by simply measuring from a few accessible points on the structure. Furthermore, natural frequency is less contaminated with surrounding noise (Qiao et al., 2011). Change of natural frequency alone was not sufficient to locate the location of structural damage (Salawu, 1997). A more robust application of dynamic based method for damage detection is based on mode shape evaluation. Mode shape approach as damage assessment indictor give benefit where mode shape is less sensitive to the environmental effect such as temperature as compared to natural frequencies (Robert, 1995).

One example application of a large plated structure used as a primary structure is steel sheet pile. Steel sheet pile has been widely utilized in many fields and famously been applied as temporary retaining wall in cofferdam as well as a permanent retaining wall in quays, harbors, and river revetment structures. During the service life of such a structure, the deterioration of this structure can occur due to aging and degradation mechanism due to exposure to marine environment which accelerated the corrosion process. Many field surveys depict that most marine environment structures suffer severe corrosion and excessive loss of material in splash zone followed by submerge zone. The damage cases in this study were designed to simulate the corrosion problem of a plated marine structure with the concentration of corrosion in center and bottom part of the thin plate. The corrosion problem in center part represent the damage in splash zone, while the damage case was concentrated in bottom part represent the loss of thickness problem in submerged zone of marine structure.

The significance of this work is to discuss fast and reliable method to evaluate the presence of damage in plated structures and further to assess sensitivity of plate structure undergoing degradation by fundamental modal analysis. The presence of structure deterioration like corrosion and loss of thickness affects the system behavior because its change the dynamic characteristics of the structure hence cause the vibration characteristics turn to be complicated. The focus of this paper is to study vibration characteristics of square plate and rectangular plate undergoing loss of thickness problem using finite element (FE) analysis by Abaqus software. The modal properties from undamaged FE model is referred to as baseline reference. The size of damage, position, and depth of loss of thickness varied for different damage cases. The percentage of the thickness reduction indicating damage severity was varied from 0% of baseline model up to 90% to further examine the sensitivity of the mode shape and reduction of natural frequencies in terms of the presence of different sizes and levels of damage severity.

METHODOLOGY

In this study, the free vibration of two types of plate case was considered, which were square plate and rectangular with different aspect ratio lengths, a, to width, b. The ratio a/b for square plate is equal to 1 while for rectangular plate is equal to 10. Damage assessment on the square plate model was designed to demonstrate local damage inspection in a small range and more localized area, while the rectangular plate was modelled to represent the damage assessment on global assessment and wide area of plated structure.

Finite Element Analysis and Modal Analysis

The plate models were construct using three-dimensional finite element analysis with a programming language called Abaqus, version 6.14. Eigenvalue analyses were performed to obtain natural frequencies and mode shapes. The Lanczos eigensolver in Abaqus was chosen in this analysis to solve matrices. The material properties of the steel considered in this study were: density, ρ = 7850 kg/m3; Poisson's ration, v = 0.3; and Young's modulus, E = 210 GPa. The dimension of the square plate is 0.3m x 0.3m whereas rectangular plate is 3.0m x 0.3m with both types of plate having the same intact thickness, h = 10mm. The plate was modeled using S4R elements, which are four node conventional shell elements with reduced integration. Uniform sizes of elements; 5mm and 25mm were set for the square and rectangular plates, respectively. The boundary conditions were set as simple support for all edges of the plate.

Damage Case Simulation

In this investigation, a total of four damage cases for each type of plate were numerically simulated with two different positions in each case. In the first case, damage was modelled at the center of the plate, while in damage case 2, damage was concentrated at the end part of the plate. In order to simulate the small and large damage, the size of damage area was categories in two cases which are small area and large area. The damage size of 2.5% of the total area represents small and localized damage, whereas the large area represents 10% of the total area represent large damage for both type of plate.

Constant plate flexural stiffness $D = Eh3/12(1 - v2)$ was set for all elements in the baseline model, while the damaged plate was modelled by reducing the flexural stiffness of the selected elements. The reduction of flexural stiffness was achieved by reducing the thickness of elements in the damaged region. The level of cut depth increased from 0% of intact model to 90% and from 0% of intact model to 50% for both square plate and rectangular plate correspondingly. The thickness of plate, which is 10mm for baseline model, was reduced to 7.0mm, 4.0mm, and 1mm to indicate 30%, 60%, and 90% of thickness reduction cases, respectively. Variations in thickness reduction were used to represent the level of severity of damage; higher thickness reduction shows that the affected area is more severely damaged. Detailed descriptions of damage cases scenario and the area of reduced stiffness, together with the position of reference line for each case, are shown in Figure 1 and Figure 2.

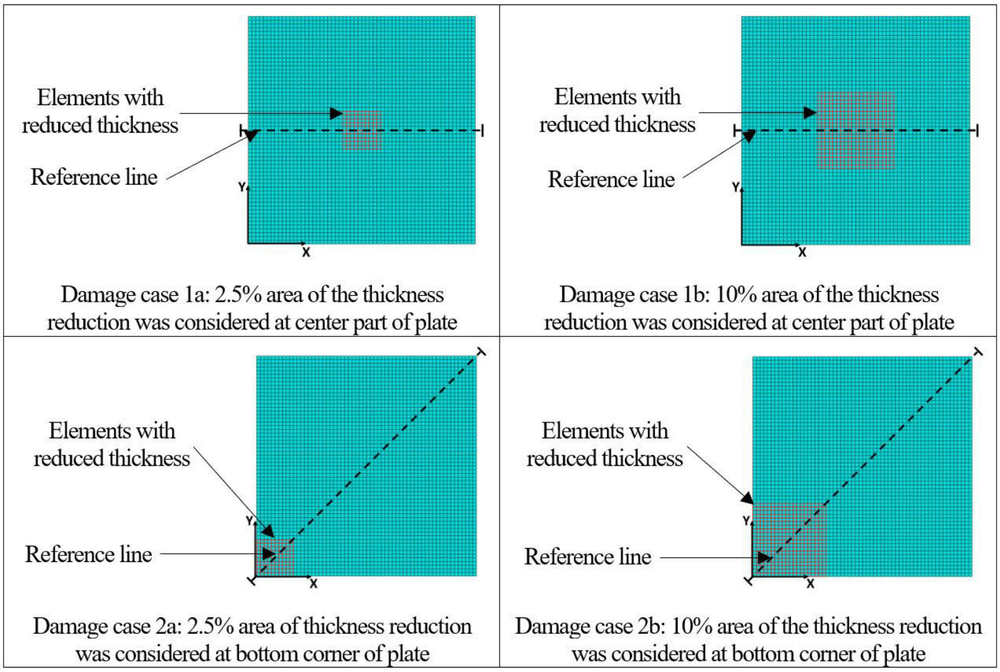


Figure 1. Details of damage case scenario in square plate

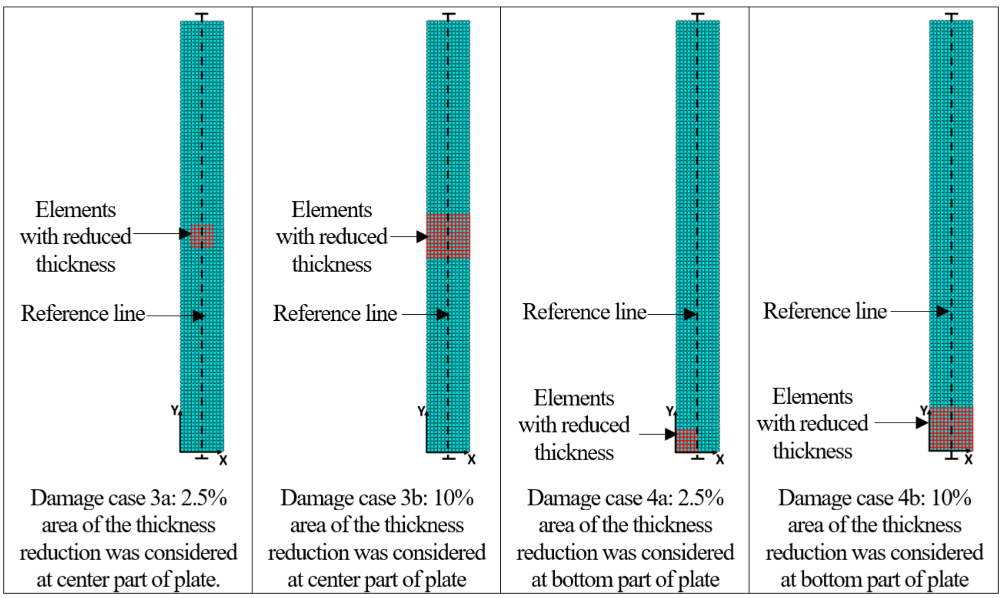


Figure 2. Details of damage case scenario for rectangular plate

RESULTS OF MODAL ANALYSIS AND DISCUSSION

Verification of Finite Element Analysis

To confirm the results of FE analysis, validation of natural frequencies with theoretical values was computed using Equation (1) for simply supported boundary condition in all edges of the plate (Leissa, 1969) expressed as:

$$\omega_{mn} = \sqrt{\frac{D}{\rho h}}\left(\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right) \quad (m, n = 1,2,\dots,\infty) \tag{1}$$

where D is the flexural stiffness; ρ is the density of the plate; h is thickness of the plate; ω is the natural frequency; and a and b are length and width of the plate, respectively. Table 1 shows the result of the comparison between FEM and theoretical method. There is good agreement between FEM and the theoretical equation.

Table 1. Comparison of frequency parameters by FEM and theoretical equation

Type		Square plate (a/b = 1)			Rectangular plate (a/b = 10)		
Methods		FEM	Theoretical by Eq. (1)	Percentage of Deviation (%)	FEM	Theoretical by Eq. (1)	Percentage of Deviation (%)
Modes	1	537.46	546.35	1.63	277.62	275.91	0.62
	2	1345.96	1365.87	1.46	285.57	284.10	0.51
	3	1345.96	1365.87	1.46	298.86	297.76	0.37
	4	2130.28	2185.40	2.52	317.51	316.88	0.20
	5	2691.40	2731.75	1.48	341.56	341.47	0.03
	6	2692.02	2731.75	1.45	371.07	371.52	-0.12
	7	3448.49	3551.27	2.89	406.06	407.03	-0.24
	8	3448.49	3551.27	2.89	446.59	448.01	-0.32
	9	4562.76	4643.97	1.75	492.70	494.45	-0.36
	10	4562.76	4643.97	1.75	544.42	546.35	-0.36

Modal Analysis Results of Baseline Model

The further investigation into first few modes of vibration is important because this mode contains higher vibration energy of the system compared to subsequent modes. The first few modes of vibration, which contain a lower frequency, indicate the global assessment of the structure which give advantage to locate the local change in the structure. First 6 mode shapes, and its corresponding natural frequencies were extracted from modal analysis of the baseline model, as shown in Figure 3 and Figure 4 for both square and rectangular plate, respectively.

The mode shape describes the pattern in which the plates vibrate on its own natural frequency. In the first mode shape of vibration for m = 1 and n = 1, vibration occurs in the whole plate, which causes the plate to move up and down regardless of the plate aspect ratio. Mode 2 and mode 3 of square plate have an identical mode shape pattern, where there are two independent regions of vibration separated by a nodal line in the middle of the plate. In mode 4, there are four independent regions that vibrate alternately up and down. Further, mode 5 and mode 6 are also described as identical modes, with nearly equal values of natural frequency but different patterns of vibration. Both mode 1 and mode 5 show that the vibration is dominant at the center part of the plate.

On the other hand, for the mode shape of rectangular plate case, there is increase in number of independent region of vibration as the mode number increases. Each independent region vibrates up and down alternately. The first mode represents the global vibration of the structure. With an increase in mode number, vibration tends be more localized in a specific region.

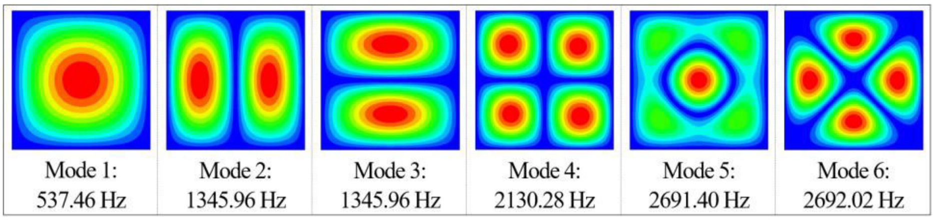


Figure 3. The first sixth mode shape and natural frequency of intact square plate

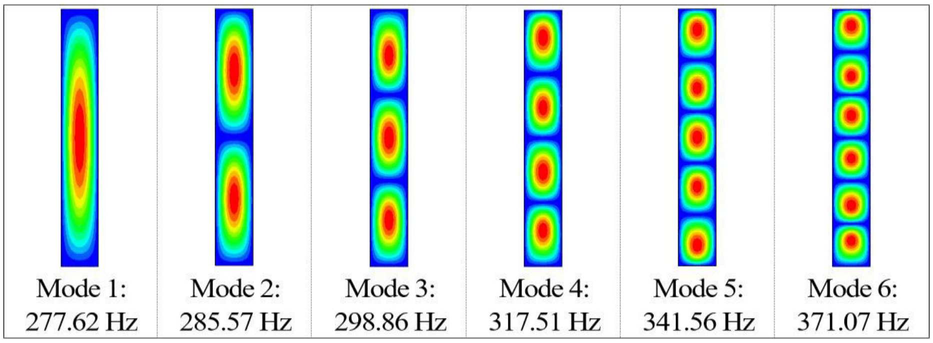


Figure 4. The first sixth mode shape and natural frequency of intact rectangular plate

Results and discussion of damage cases model

Based on the concept that damage alters the geometrical properties and mass properties of structures, it was expected from the results that at the introduction of damage, significant changes of natural frequency and mode shape of the structure take place. The different positions of loss of element section and depth of cut-off are factors that contribute to the amount of reduction of natural frequency and localization of mode shape in the damaged region. In order to express the effect of damage towards frequency change, a simple non-dimensional correlation between baseline model and damaged model was determined as a percentage of frequency change as shown in Equation (2).

$$\mathrm{R}(\%) = \frac{\omega_{\mathrm{u}} - \omega_{\mathrm{d}}}{\omega_{\mathrm{u}}} \text{ x } 100 \tag{2}$$

In Equation (2), ω_u is the natural frequency for undamaged model and ω_d is the natural frequency for damaged model. At a glance, with an increase in loss of thickness from 0% indicating an intact model to 90% thickness reduction in ranking a damaged region, a significant decrease of natural frequency and localization of mode shape in the damaged region can be observed.

Square Plate

Changes of natural frequency and switching of mode shape due to the presence of damage in two different positions and sizes for the square plate case are discussed in this stage. For detailed investigation of change of mode shapes in the presence of four damage case scenarios for square plate, mode 1, mode 2, and mode 5 were extracted for damage case 1, whereas mode 1, mode 2 and mode 4 were selected from modal analysis for further discussion of the effect of the presence of damage case 2 in plate structure. Selection of mode was based on the mode shape that possessed dominant vibration in the designated damage region.

Damage Case 1

The reduction of natural frequency is one of the indicators of the presence of damage in the structure. With 2.5% of damage area in square plate, the reduction of natural frequency can be observed, as shown in Figure 5. Mode 1 and mode 5 show maximum natural frequency reduction, followed by mode 4, mode 6, mode 2 and mode 3. The higher reductions in mode 1 and mode 5 occur because damage was concentrated in the dominant vibration region. The details of mode shape and displacement of mode shape variation due to presence of damage case 1 was shown in Table 2. The presence of damage was able to be detected by reduction frequency; further, the location and size of damage can be predicted based on change of mode shape from baseline model. The displacement graph represents the displacement of the mode shape along the reference line of plate, as illustrated in Figure 1. The increase of damage from intact model to 90% thickness reduction case causes a slight change of mode shape in the damage region based on displacement graph. Localization of displacement graph curvature in the damaged region can be seen in 90% thickness reduction and mode shape results show that the vibration was dominant in the damaged region as severity of damage increased. A clearer observation of frequency change and localization of damage in mode shape was expected in more severely damaged areas, indicating a higher percentage of damage area.

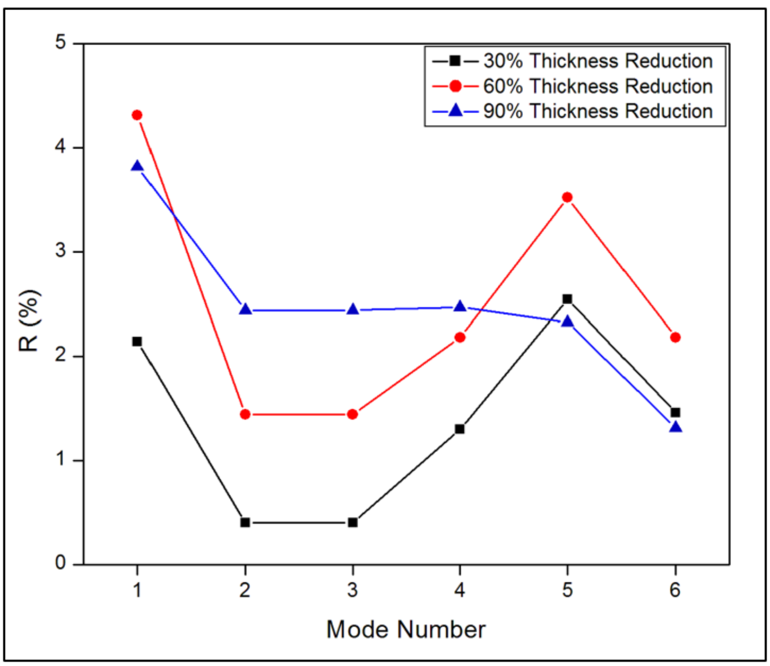
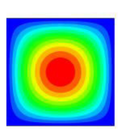
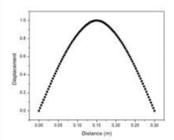
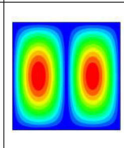
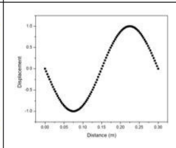
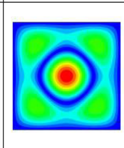
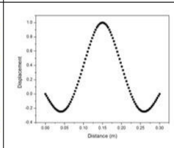
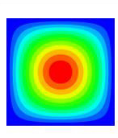
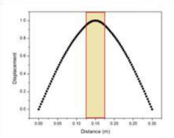
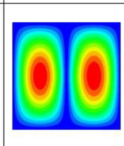
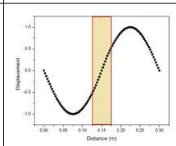
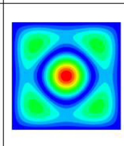
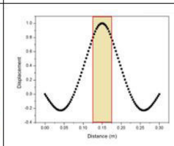
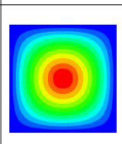
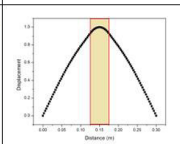
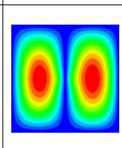
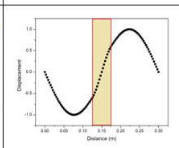
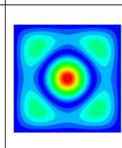
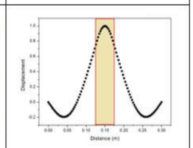
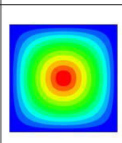
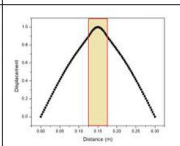
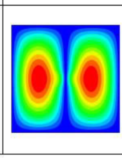
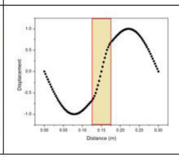
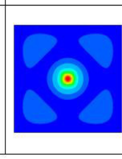
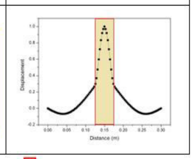


Figure 5. Reduction of natural frequency in the first six modes for damage case 1 (2.5%) in square plate

Table 2. Switch of mode shapes and displacement mode shape due to 2.5% designated area of damage case 1

Reduction	1st Mode		2nd Mode		5th Mode	
	Mode Shape	Displacement	Mode Shape	Displacement	Mode Shape	Displacement
Intact						
30%						
60%						
90%						

Damage region

The greatest deviation of mode shape was expected to occur around the damage region and this information is valuable information to located the location of damage in structure for further investigation. The increase of damage area from 2.5% to 10% caused a large deviation, with values of 65.55% for natural frequency in mode 5 of 90% thickness reduction, as shown in Figure 6. The change of natural frequency in 30% reduction was almost constant for all six modes and the results obtained show that increasing of thickness reduction to 60% cause the percentage deviation of natural frequency also increase. The change of natural frequency for each mode in 90% thickness reduction is higher than all other cases except for mode 1. Table 3 summarize graphically the change of mode shape and displacement mode shape due to 10% area of damage case 1. In 30% thickness reduction, the mode shape results do not show distinct changes from baseline model. While in 60% case of thickness reduction, a small change in graph of displacement mode shape towards the damage region was observed and lastly in 90% damage, mode 5 deviates more and only vibrates up and down in the damaged region. There was almost zero displacement observed near the specified damaged region.

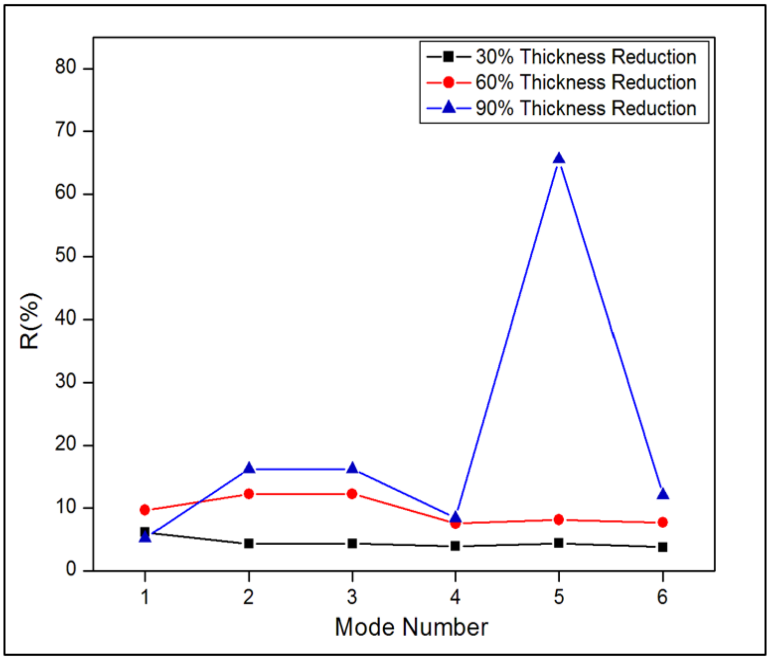
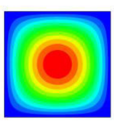
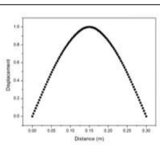
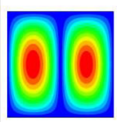
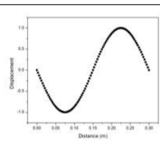
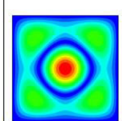
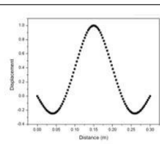
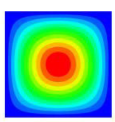
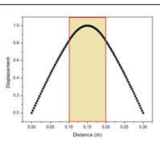
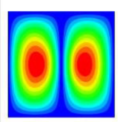
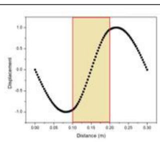
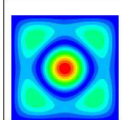
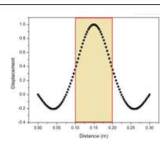
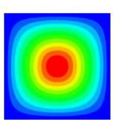
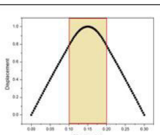
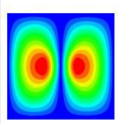
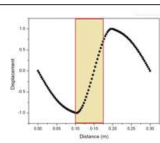
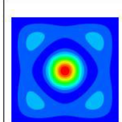
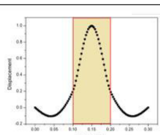
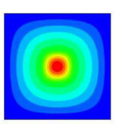
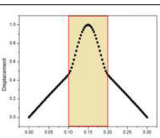
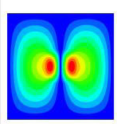
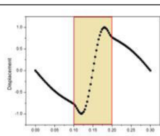
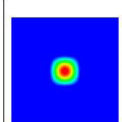
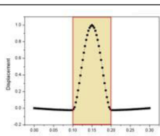


Figure 6. Reduction of natural frequency in the first six modes for damage case 1 (10%) in square plate

Table 3. Switch of mode shapes and displacement mode shape due to 10% designated area of damage case 1

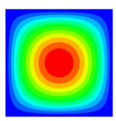
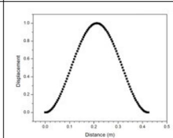
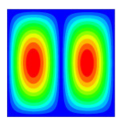
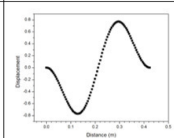
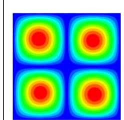
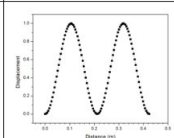
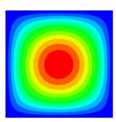
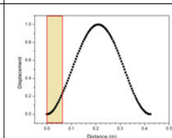
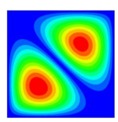
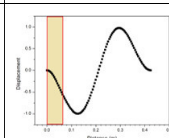
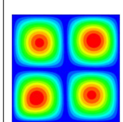
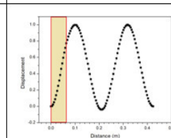
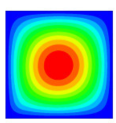
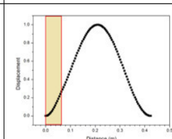
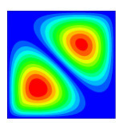
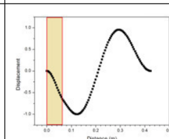
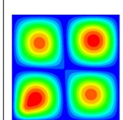
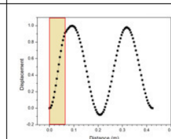
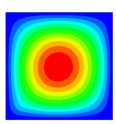
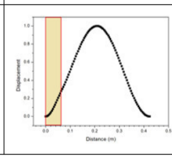
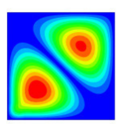
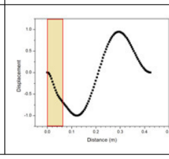
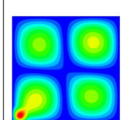
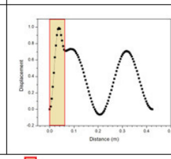
Reduction	1st Mode		2nd Mode		5th Mode	
	Mode Shape	Displacement	Mode Shape	Displacement	Mode Shape	Displacement
Intact						
30%						
60%						
90%						

Damage region

Damage Case 2

The effect of boundary condition for the damage case 1 was not as great as that of damage case 2, since the location of the damage case 1 was located at center part of the plate, whereas in damage case 2 the boundary condition might have significant effect on the results obtained. Results from Figure 7 and Table 4 summarize the effect presence of damage case 2 in a 2.5% damage area in term of mode shape and displacement of mode shape in diagonal axis of plate. In a graph of frequency change, mode 2, followed by mode 4, shows higher natural frequency deviation in this damage scenario. On the other hand, mode 3 was not able to detect the presence of this damage since almost zero deviation of natural frequency for all the three damage cases. This related with the position of damage which located in passive region of vibration pattern in mode shape 3. Thus, the selection of mode shape for further investigation state of damage in structure is an important criterion to consider. The displacement graph of mode 4 show the localization of mode shape in the damaged region whereas mode 1 and mode 2 does not have higher sensitivity towards the presence of this damage, since the displacement mode shape does not deviate much from the intact case.

Table 4. Switch of mode shapes and displacement mode shape due to 2.5% designated area of damage case 2

Reduction	1st Mode		2nd Mode		4th Mode	
	Mode Shape	Displacement	Mode Shape	Displacement	Mode Shape	Displacement
Intact						
30%						
60%						
90%						

Damage region

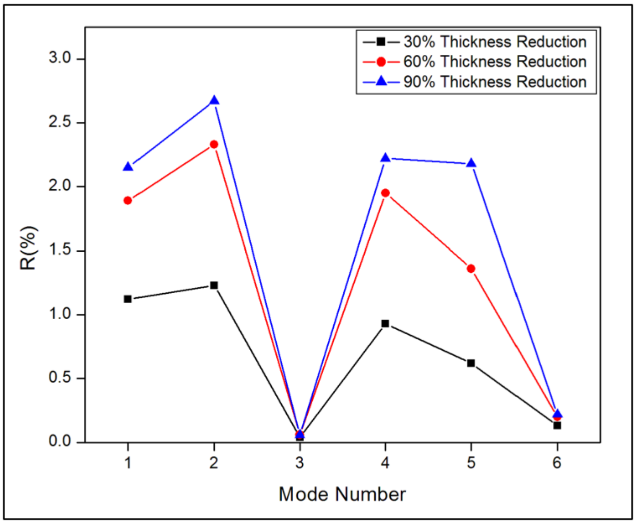


Figure 7. Reduction of natural frequency in the first six modes for damage case 2 (2.5%) in square plate

Figure 8 and Table 5 present the graphical changes of modal parameters for mode 1, mode 2 and mode 4 due to damage case 2 in 10% of damage area. A higher frequency change was observed in mode 2 in 90% thickness reduction case, with value of 49.85%. As the increase of damage size from 2.5% to 10%, the deviation of frequency in mode 3 still the small compare to others modes confirm that mode 3 is unsensitive towards the presence of damage case 2. For mode 1, the frequency change does not deviate much between each case of thickness reduction, while in mode 4, mode 5 and mode 6, there is great change of natural frequency from 60% to 90%. Mode shape in mode 4 shows that the damaged region takes higher amplitude of vibration displacement from 30% up to 90%. The displacement mode shape is towards 90% thickness reduction, and there is a new independent region created in the damaged region which vibrated with higher amplitude of displacement.

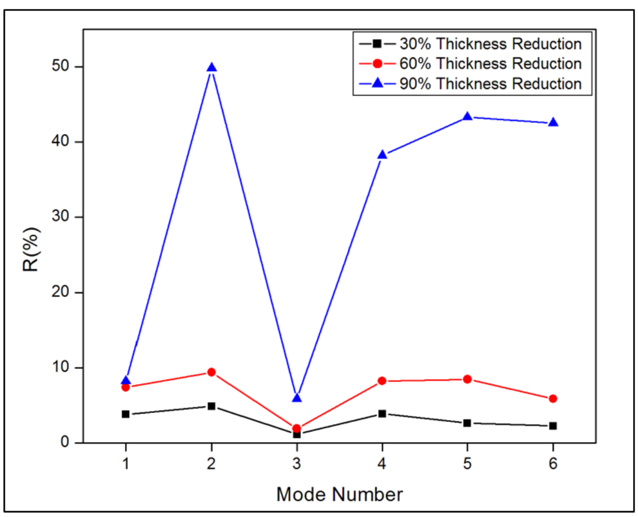
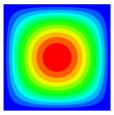
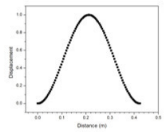
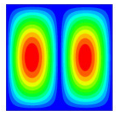
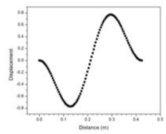
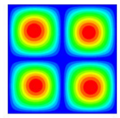
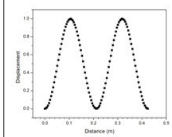
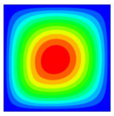
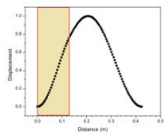
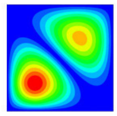
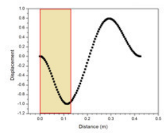
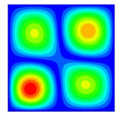
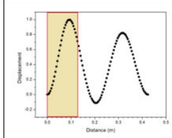
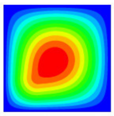
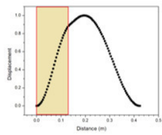
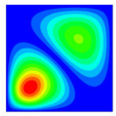
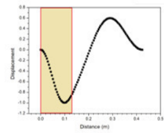
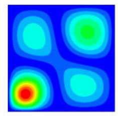
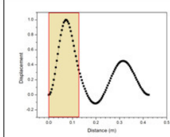
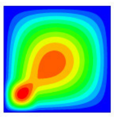
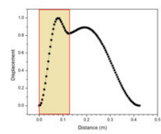
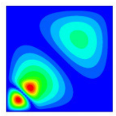
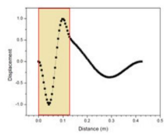
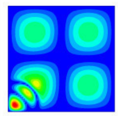
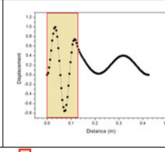


Figure 8. Reduction of natural frequency in the first six modes for damage case 2 (10%) in square plate

Table 5. Switch of mode shapes and displacement mode shape due to 10% designated area of damage case 2

Reduction	1st Mode		2nd Mode		4th Mode	
	Mode Shape	Displacement	Mode Shape	Displacement	Mode Shape	Displacement
Intact						
30%						
60%						
90%						

Damage region

From the results obtained, the reduction of natural frequency increased with an increase of damage level and large deviations of natural frequency occurred when the damage was located in dominant vibration region of the mode. On the other hand, when the damaged was located in the passive region of vibration pattern, only small changes of natural frequency were observed. The mode shape also shows same pattern where the localization of mode shape is large when the mode is sensitive towards the presence of damage. The localization of mode shape in the damaged region for small and large damage in different position shows that mode shape was able to identify the size and location of damage. Nonetheless, mode 1 which is global mode that give global view of the structure is suitable to assess the presence of damage and further can be used to predict the location of damage. Results from global mode can be used for excitation of more local mode which possess higher excitation frequency.

Among all of the factors examined, small damage size shows less change in frequency and curvature of mode shape localization as compared to 10% damage case, where there is significant change in both modal parameters. Even though a small change was introduced to the structure, both modal parameters were able to detect the presence of damage from reduction of natural frequency and further predict the location and size of damage from displacement of mode shape.

Rectangular Plate

The assessment of damage in rectangular plate represents the inspection of a large region of plated structure. In this stage, the damage case was considered only up to 50% thickness cut off. This is because mode one, which has the lowest excitation frequency, was highly sensitive towards the presence of damage even for localized damage case in this study, which represent 2.5% damage case. The reduction of natural frequency and localization of damage in displacement mode shape will be discussed further.

Damage Case 1

The graph in Figure 9 represents the deviation of natural frequency from baseline model when damage was located in middle part of rectangular plate. Mode 1 show large deviation, and the natural frequency was uniformly reduced as the increase of damage severity. Among all modes, mode 2 shows lower reduction since the position of damage was located in a nodal line which represents the passive region of mode shapes. Table 6 presents the switch of mode shape towards this damage and as can be seen, mode 1 has higher sensitivity towards the presence of damage. For this reason, only mode 1 will be further discussed for the damage assessment in rectangular plate case.

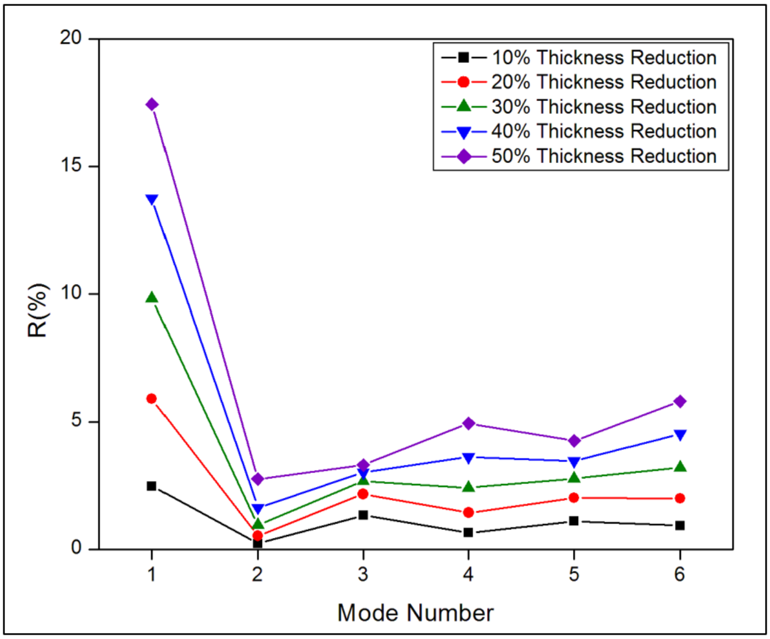
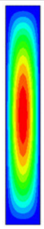
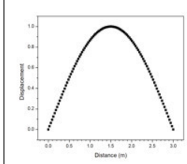
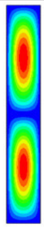
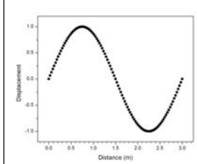
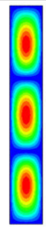
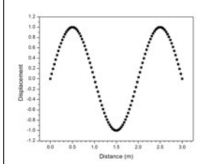
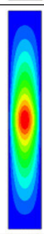
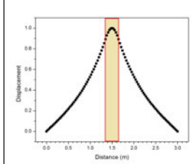
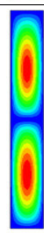
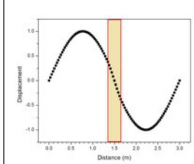
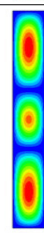
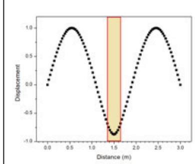
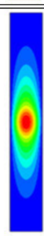
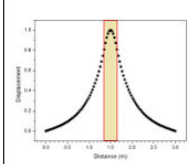
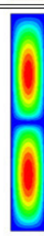
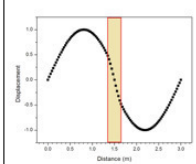
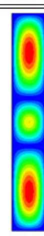
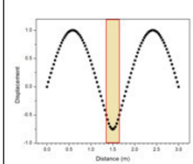
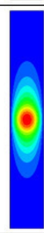
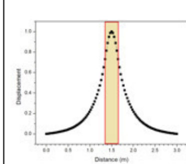
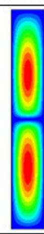
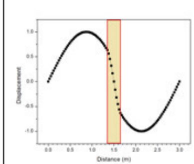
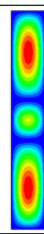
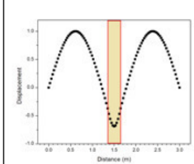
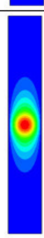
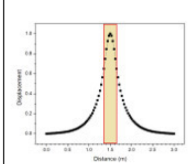
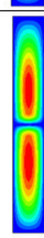
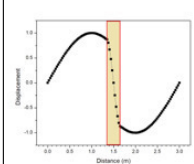
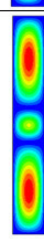
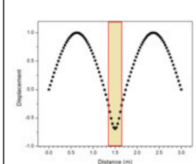
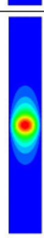
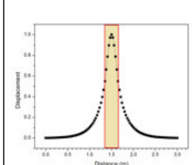
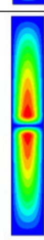
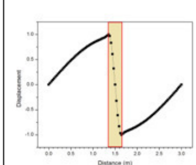
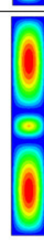
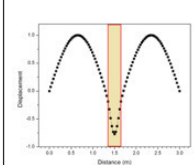


Figure 9. Reduction of natural frequency in the first sixth modes for damage case 1 (10%) in rectangular plate

In addition, the vibration is dominant in the damage region as the severity of the damage increased from intact model to half of thickness reduction. In 1mm thickness reduction, the localization of mode shape towards the damage region can be seen from both mode shape and displacement mode shape figure. In mode 2, even the damage was modelled in passive vibration region, the switch of mode shape towards damage region can be clearly seen. The vibration region acquires higher amplitude of displacement as the severity of damage increases.

The sensitivity of modal parameter due to decrease of damage area for damage case 1 is illustrated by Figure 10 and Table 7. Mode 1 shows higher frequency change followed by mode 3 and mode 5. The frequency change in mode 2 is hard to identify for all thickness reduction cases. The curvature of displacement graph of mode 1 increases from intact to 50% thickness reduction.

Table 6. Switch of mode shapes and displacement mode shape due to 10% designated area of damage case 1

% Reduction	1st Mode		2nd Mode		3rd Mode	
	Mode Shape	Displacement	Mode Shape	Displacement	Mode Shape	Displacement
Intact						
10%						
20%						
30%						
40%						
50%						

Damage region

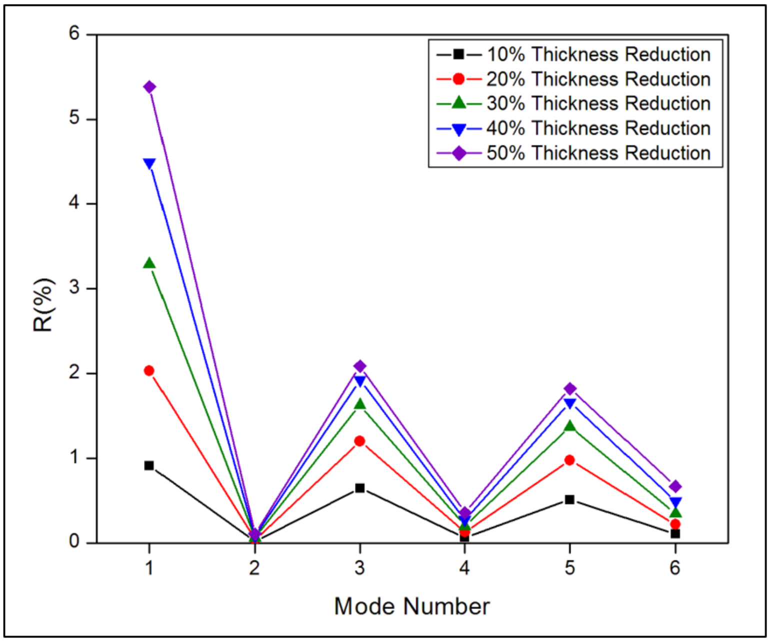
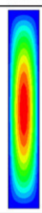
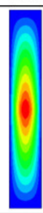
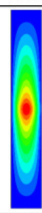
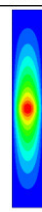
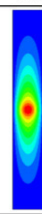
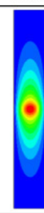
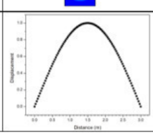
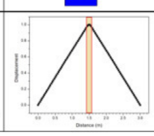
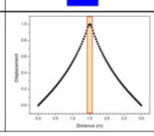
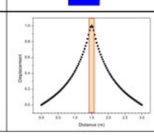
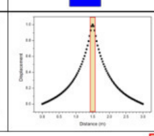
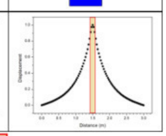


Figure 10. Reduction of natural frequency in the first six modes for damage case 1 (2.5%) in rectangular plate

Table 7. The variation of first mode due to varies thickness reduction in designated damage region for damage case 1 (2.5% area)

% Reduction	Intact	10%	20%	30%	40%	50%
Mode Shape						
Displacement						

Damage region

Damage Case 2

In this section, the position of damage was change from the middle to the end of plate. Both Figure 11 and Table 8 summarize modal parameter changes towards the concentration of damage in the end plate. The natural frequency change increased from mode 1 to mode 6 as the damage became severe at the end plate in a uniform pattern. Even with an increasing reduction in frequency, the value of change was not significant. Overall change was less than 1% and maximum change was 1.35% in mode 6 for 50% thickness reduction.

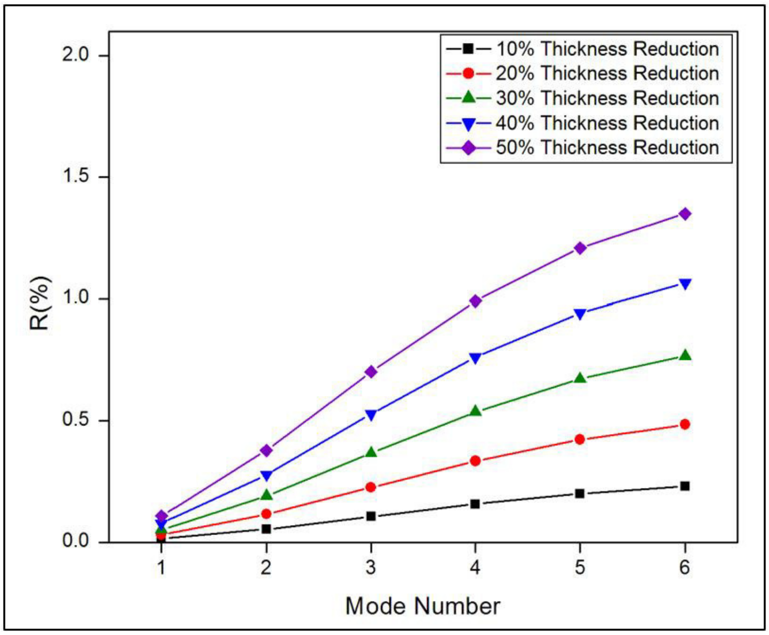
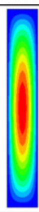
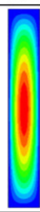
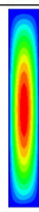
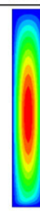
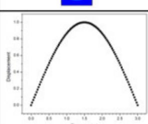
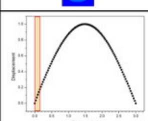
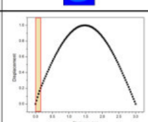
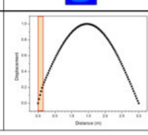
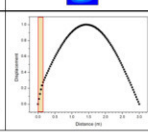
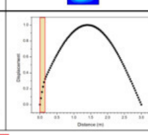


Figure 11. Reduction of natural frequency in the first six modes for damage case 2 (2.5%) in rectangular plate

Table 8. The variation of first mode due to varies thickness reduction in designated damage region for damage case 2 (2.5% area)

Reduction	Intact	10%	20%	30%	40%	50%
Mode Shape						
Displacement						

Damage region

Figure 12 represents the reduction of natural frequency in first 6 mode shapes due to damage case 2 with 10% damage area. Table 9 presents changes in mode 1 due to this damage.

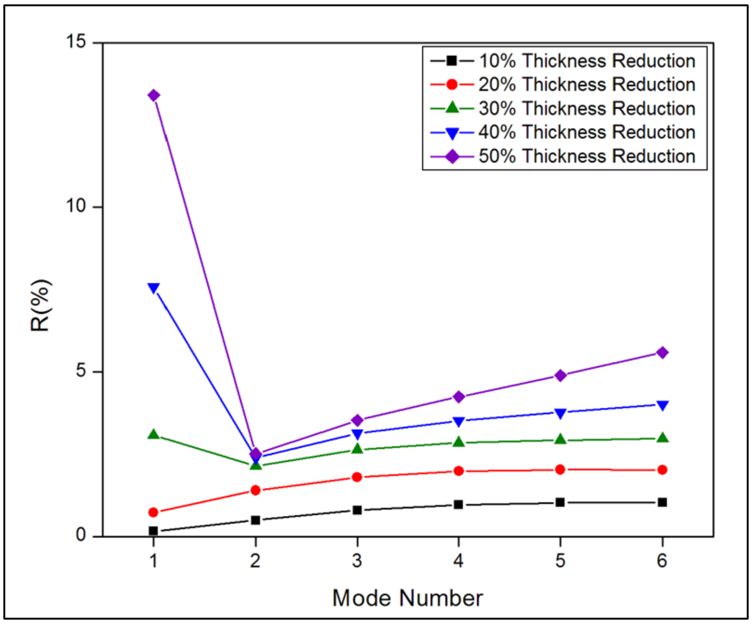
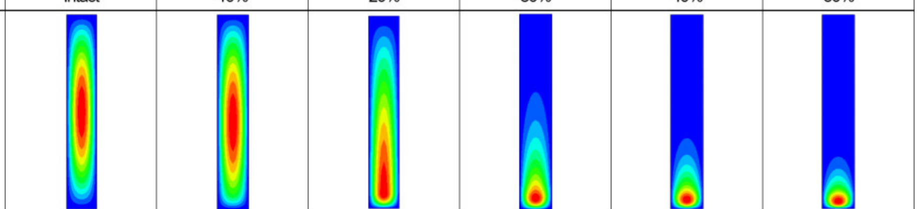
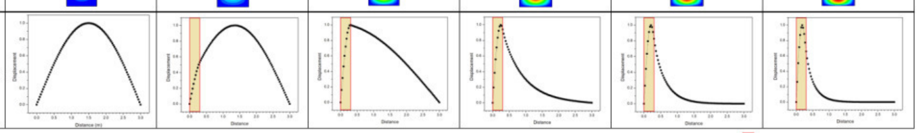


Figure 12. Reduction of natural frequency in the first six modes for damage case 2 (10%) in rectangular plate

Table 9. The variation of first mode due to varying thickness reduction in designated damage regions for damage case 2 (10% area)

Reduction	Intact	10%	20%	30%	40%	50%
Mode Shape						
Displacement						

Damage region

The observations from rectangular plate show that even though the reduction of natural frequencies was small at less than 1%, there is clear localization of the displacement of mode shape on the damage area. All thing considered, the presence of a cut-off in the rectangular plate case was able to be detected by the modal parameter as compared to square plate case. Thus, changes in main modal parameters like frequency and mode shape can be further used as indicators of the presence of damage in a large plated structure.

CONCLUDING REMARK

The present study focuses on the identification of the presence and position of damage in a plate structure using two main parameters from eigenvalue analysis, which are natural frequency and mode shape. The observation from the results shows that:

1. Changes in natural frequency from baseline model can be used as indicators of the presence of a state of damage.
2. Next, it was confirmed that mode shape is another indicator which can be applied to indicate the presence and additionally the location and size of the damage.
3. It is reasonable to conclude that significant reduction and change in frequency and mode shape leads to determination of the presence, location, and size of the existence of structural damage, but this strongly depends on severity of damage.

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CONCEPTUALISING 4CS IN CONSTRUCTION PROJECT TEAM INTEGRATION

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Abstract
A construction project team is comprised of personnel from different backgrounds working together to achieve common goals. Integration is necessary so that the team can leverage its collective skills, knowledge and experience to achieve success. However, the benefits of integration have yet to be fully understood and optimised, due to an inconsistent shared vision, poor communication and coordination, and the lack of cooperation and collaboration from team members. This study explores team integration in the construction industry. A new team integration concept of 4Cs (Communication, Coordination, Cooperation and Collaboration) has been developed through a critical review of existing theories. This study contributes to the understanding of complex integration issues in construction project teamwork. The newly conceptualised model can serve as a framework for stakeholders in organising project teamwork and act as a catalyst to improve project performance.

Keywords: *Communication, coordination, cooperation, collaboration, construction projects.*

INTRODUCTION

Construction projects are temporary, complex, and dynamic. Many organisations undertake construction project. A construction project team is multidisciplinary comprising members from different disciplines having diverse expertise, characteristics, culture, and style of management (Ibrahim et al., 2013). Each member has complementary roles that contribute to the completion of the project (Kubicki et al., 2006). In other words, though each of the members performs distinct roles and functions they possess closely related knowledge and skills (Radosavljevic and Bennett, 2012).

Integration refers to harmonious teamwork crucial for successful projects (Baiden and Price, 2011). Integration is needed to merge different disciplines with different goals, needs and cultures into a cohesive and mutually supporting unit (Kirsila et al., 2007). It also emphasises the optimisation of combined expertise and technical knowledge (Ika, 2012). In ideal cases, effective integration promotes better project performance, especially regarding innovation (Ibrahim et al., 2013; Baiden and Price, 2011; Egan, 2012; Latham, 1994; Rahman and Kumaraswamy, 2012). The major challenges of integration lie in handling the dynamics of inter-organisational teams due to unavoidable changes in leadership, authority, goal orientation, mental model, relationship, and mutual performance monitoring (AIA, 2007; Kent and Becerik-Gerber, 2010). The integration process is embedded with structural and cultural difficulties regarding incompatible goals, poor communication and reluctant participation from team members (Constructing Excellence, 2006).

Effective teamwork requires active integration through communication, coordination, cooperation and collaboration (Suprapto et al., 2015). The communication, coordination, cooperation, collaboration or C’s theoretical perspective is an avenue of research employed to discuss the integration issues in many industries (Zomorroddin, 2011; Martinez and Davizon, 2015; Balakrishnan et al., 2011). The C concepts are also extensively used in the construction project management studies. However, different researchers and authors remain focused on individual components of the C concept. For example, cooperation was the focus of Balakrishnan et al. (2011) and Rahman and Kumaraswamy (2008) and coordination was the focus of Neeraj Jha and Misra (2007) and Tey et al. (2012). These are a reductionist approach.

In some cases, the C concepts can be used interchangeably (Denise, 2007). This is particularly the case when discussing collaboration and cooperation in project team integration (Vaaland, 2004). It is attributable to team integration including mutual trust, aligned effort and shared performance. Vagueness in the definition of the Cs and lax application exacerbates the poor conceptualisation of the C concept in construction literature.

This study seeks to bridge this knowledge gap by conceptualising an inclusive model of the 4Cs as necessary facets of the construction project team integration. Through a comprehensive review of literature, this paper provides a conceptual structure for the 4Cs in construction project teams. It is anticipated that the paper will serve as a guideline for practitioners to make critical decisions on using communication, coordination, cooperation and collaboration to promote team integration in construction projects.

COMMUNICATION, COORDINATION, COOPERATION AND COLLABORATION (4CS) CONCEPT IN GENERAL

The embedment of the Cs concept is not a new phenomenon. This section discusses its application in other industries to understand integration issues from different perspectives.

Zomorrodian (2011) emphasised the importance of the 3Cs (Cooperation, Collaboration and Coordination) in making and achieving strategic plans in the general corporate business. Cooperation, in the author's point of view, is the strategic implementation process that emphasises partners working together as a team to achieve organisational goals and objectives. Collaboration is the interdependence and an innate need to pool strength to build capacity, and coordination is the alignment of activities beginning with the awareness to make the successful implementation of the strategic plan.

Similarly et al. (2005), Denning and Yaholkovsky (2008), and Steinmacher et al. (2010) used integrated 4Cs (Communication, Coordination, Cooperation and Collaboration) to explain the complex and dynamic nature of integration in the Information and Communication Technology (ICT) industry. In their studies, each C process has an interrelationship and/or prerequisite to another C's process. Communication, coordination and cooperation are the underlying collaboration while all the Cs are the complementary processes of integration. Some ICT scholars altered the theoretical model of the existing 4Cs. For example, Shah (2013) added "contribution" to mutual support within the team and Fuks et al. (2004) incorporated "commitment" [30].

Badiru (2008) proposed the Triple C Model (Communication, Cooperation and Coordination) to address the human and social aspects of project management. It elucidates communication as the foundation for cooperation, which in turn is the foundation for coordination to contribute jointly to project success. The Triple C Model facilitates a systematic and generic approach to project planning, organising, scheduling and controlling.

Other than that, Martínez-Olvera and Davizon-Castillo (2015) suggested four abilities necessary for the Supply Chain Management (SCM) value creation process from the theoretical perspective of the 4Cs. In their study, the authors opined that communication is the ability to share key information; coordination is the ability to match the supply chain partners' capabilities by harmonising the individual actions/decisions; collaboration is the ability to establish mutual trust by adjusting the individual behaviour in accordance with a jointed decision-making and benefits and risks sharing; and cooperation is the ability to support strategic commitments by aligning the individual strategic, tactical, and operational decisions with the common objectives, goals, and policies.

Furthermore, Gulati et al. (2012) categorised cooperation and coordination as the two facets of a collaboration process to scrutinise strategic alliances between strategic and operational levels. This study presented a holistic approach to gain insight into the reality of a strategic alliance.

Lejeune and Yakova (2005) used the 4Cs concept (Communication, Coordination, Collaboration and Cooperation) to distinguish the relational structure among supply chain partners based on four attributes of goal congruence, trust level, information sharing, and decision-making. The continuum refers from the communicative supply chain, coordinated supply chain, collaborative supply chain to cooperative supply chain. Each supply chain configuration experiences different degrees and outcomes from the proposed attributes.

Balakrishnan et al. (2011) suggested three levels of collaboration - co-acting team, coordinated team and integrated team. The authors used this to explain the nature and experience of an integrative research team which have members working across fields and with different expertise based on the attributes of collaboration focus; collaboration description; type of interdependence; strategies to implement; the difficulty of implementing; and benefits of collaboration.

Based on the review, the 4Cs concept can be broken down to gain insight into how each C concept is responsible for the different notion of integration. The hierarchy rank and the dimensions of integration are the two meaningful sets of differentiation criteria. According to Table 1, integration hierarchies can be summarised into four ranks. Variance in hierarchy rank of integration is contingent on different cognitive judgements by authors relating to the C's conceptual validity and it is also constrained by the scope of the study. Meanwhile, integration issues, in general, can be simplified into five dimensions as per Table 2.

Table 1. Integration hierarchies in general

Hierarchy Rank				References
I	**II**	**III**	**IV**	
Coordination	Collaboration		Cooperation	[14]
Communication	Coordination	Cooperation	Collaboration	[15]–[17]
Communication	Cooperation		Coordination	[18]
Communication	Coordination	Collaboration	Cooperation	[19], [21]
Communication	Cooperation		Collaboration	[20]

Table 2. Dimensions of integration in general

No.	Dimensions	References
1	Degree of integration	[15]–[17], [29]–[31]
2	Hierarchy level of management	[18]–[20]
3	View of planning and decision making	[14], [18]
4	Form of relationship	[21], [22]
5	Type of team structure	[21], [22]

RESEARCH METHOD

This study was based on an extensive review of literature. It employed communication, coordination, cooperation and collaboration as the four major concepts that explain team integration. The review was conducted in three parts.

Firstly, literature was on the 4Cs concept from many industries, including corporate business, ICT, SCM, and Research and Development (R&D) was reviewed. This is a significant effort to explore domains of integration from a variety of perspectives so it can be useful ground for the conceptualisation of the 4Cs into a construction-specific context. The review was followed by the computation of integration hierarchies and the operationalisation of integration dimensions. By critical analysis, similarities and deviations of the 4Cs framework were presented to reveal the essence of the integration concept.

Secondly, literature on integration in the construction industry was reviewed. This review is important to gain fundamental knowledge about history, development and the nature of integration domains in the construction industry. The review focussed on integration issues pertaining to teamwork in construction projects to align project-orientation and teamwork. Following this, a definition of team integration in construction projects is suggested to clarify ambiguities.

Thirdly, communication, coordination, cooperation and collaboration in the construction industry are reviewed to determine their function in teamwork in construction projects. This review is important to the critical analysis of the C concepts in construction that might be compatible with the conception in other industries. It further lays a solid ground for cognitive judgement on the formulation of their associations with previously identified variables of integration. Following this is a detailed discussion of the associations between C concepts and variables of integration.

Lastly, the 4Cs framework is suggested to contribute a new domain of integration to teamwork in construction projects. Details of the framework were briefly discussed to provide holistic explanations to facilitate the learning of the core principles of the 4Cs for team integration in construction projects.

INTEGRATION CONCEPT IN CONSTRUCTION INDUSTRY

Integration was coined by several high impact white papers from the United Kingdom (UK) in the 1990s (Latham, 1994; Bennett and Jayes, 1995; Egan, 1998). Since then, it has cascaded on the global construction industry, and its development is retrievable from several domains. First, an inclusive procurement method that combines primary phases of construction project delivery, such as design and build, Integrated Project Delivery (IPD) and management contracting (Kent and Becerik, 2010). The second domain is relationally an integrated project team through relational contracting such as alliance and partnering that improves and prolongs the contractual relationship through shared ownership, shared roles and shared risks for better cooperation (Rahman and Kumaraswamy, 2008). Third, a domain on concurrent engineering, lean production and SCM that collaborate project activities for innovative and seamless design and construction deliveries (Vrijhoef and Koskela, 2000). Other mentioned domains are like Building Information Modelling (BIM) and virtual project management that provide collaborative construction project management by leading-edge computer-based methods and tools (Charalambous et al., 2013).

Integration in Construction Project Teamwork

Construction lifecycle consists of prominent stages of planning, contracting, design, construction and maintenance. Managing an increasing complexity of construction delivery requires a myriad of collective activities of a group of people than individual could accomplish separately. Pooling of diverse expertise, skills, the experience of varied stakeholders become essential practices rooted in the industry. Using a multidisciplinary team for construction projects is essential under the inter-organisational structure. The key personnel participating in a project delivery team typically include the client, designer, contractor, and other consultants, depending on project needs (Xue et al., 2007). They are mutually accountable for the project completion, and each has to remain committed to complementary roles as agreed in the contractual appointment.

The major problem facing teamwork in construction projects is inadequate integration among the varied stakeholders (Constructing Excellence, 2006; Bennet and Jayes, 1996). Team stability is threatened by poor team spirit and cohesion, low team efficacy, scepticism, blame culture and incompatible goals as the consequences that undermine the overall project performance (Levi, 2003). When distinct stakeholders are united to work as an integrated whole, the amplitude of synergy effects is hardly explained by simple summation rules of 1+1=2. Standing in the construction context, team integration in construction projects can be defined as “Interdisciplinary collaboration of project team members’ professionalism, knowledge and experience that aims to achieve transformative team working and innovative means of overall project performance” (Rahman and Kumaraswamy, 2012)

COMMUNICATION, COORDINATION, COOPERATION AND COLLABORATION IN CONSTRUCTION INDUSTRY

Each C concept is a broad subject in construction management literature. Thus, each is purposely briefly discussed in a succinct way by following a structured discussion of its- 1) functions in construction project management, 2) uniqueness in construction project team interaction and 3) importance and consequences of its presence in teamwork in construction projects.

Communication

Communication functions to interact with the individuals, groups and organisations in a construction project to perform their collective works (Badiru, 2008). As the construction project team is not homogeneous in nature (Emmitt and Gorse, 2003), construction information is exceptionally diverse and is often exchanged by interdependent interfaces (Bengi, 2011). The quality of communication is to be timely and transfers accurate information or exchange of information (Xue et al., 2007). The faster a construction project team can communicate effectively with constructive information, the faster they can establish good working relationships (Bengi, 2011). Active communication helps to establish trust and achieve empathy to promote synergy among the team members (Emmitt and Gorse, 2003). Communication is, therefore, a requisite for strategic integration in teamwork through coordination, collaboration, and cooperation (Martinez and Davizon, 2015).

Coordination

Coordination is a synchronised and aligned function in construction management (Malone and Crowston, 1990). It involves distributed managerial roles and harmonious alignment of the collective efforts towards common goals (Tey et al., 2012). In a multidisciplinary team structure, activities are collective and mutually dependent that require an aligned effort in their interaction (Chang and Shen, 2009). Coordination is essential to daily operational interactions which individual tasks typically carried out in a synchronised setting. Every effort from the interfaces is aligned with the project's goal (Xue et al., 2006).

Coordination becomes crucial when the construction project advances to the construction management stage (Higgin and Jessop, 1965). This is because the failure of coordination substantially impacts on the delivery time, the cost incurred and the quality of deliveries (Iyer and Jha, 2005). However, coordination failure also possibly arises from design development, such as design error and discrepancies that contribute to inefficient operational process in later construction stages (Hossain, 2009). The consequence is not attributable to project performance alone, but also undermines the teamwork of the project through transitions of conflict, deteriorated relationship, dispute and litigation between team members (Kubicki et al., 2006). It becomes clear that proper coordination is crucial to foster team integration.

Cooperation

Cooperation refers to the harmonious alignment of interests, objectives, and commitments through open negotiation among partners (Lin and Harding, 2007). The negotiation is the willingness to contribute resources given the expected benefit from the cooperation between parties. Often, mutual benefit is the significant incentive that drives a project team to resolve conflicts, adjust their actions, stabilise their interaction, and form stable coalitions (Scheffran and Hannon, 2007). Most cooperative efforts are long-term and offer a big scope of objective alignment through inter-organisational learning (Love et al., 2002), to foster trust-based cooperation (Lyman, 2003). As projects are temporary settings, the construction project team is likely to seek discrepant self-interests rather than collective project goal. This piecemeal type of cooperation tends to have more incompatible actions, values and goals in the team interaction (Olander and Landin, 2005). Conflict is an identifiable consequence of cooperation failure, which further causes diminished commitment (Scheffran and Hannon, 2007, withers the relationship (Doz, 1996) and at worst, leads to opportunistic behaviour (Williamson, 1985). Therefore, adequate cooperation is an essential stimulus to team functioning in the project with minimal relationship conflict.

Collaboration

Collaboration is the intensive joint efforts of a group of distinct personnel to respond to increasing complex resource efficiency of the project delivery. It mainly functions to integrate the capabilities of committed partners for delivering a successful construction project (Suprapto et al., 2015). The construction project team has its inherent set of diversities and capabilities, so transformative improvement can be achieved if the collaboration opportunity is appreciated and managed properly. However, inter-organisational collaboration as per project team can be extraordinarily complex and risky because of the need to bring together different disciplines across a network of firms (Gulati et al., 2012). It is crucial that collaboration be fostered as early as possible in project team interaction, through the definition of early goals and early involvement of key participants.

In today's IT age, the online collaborative system brought about boundless opportunities to collaborate at a faster pace. Therefore, collaboration in the construction project is also discussed in BIM, a technology-oriented synchronised and jointly working based on detailed geometry modelling (Charalambous et al., 2013). Creation of collaboration enabling technologies also crafts the needs of rigorous collaboration planning and implementation. Failures in collaboration may mean a greater amount of disputes, litigation and hostile relationships that undermine the team integration in a construction project.

LINKING 4CS CONCEPT WITH CONSTRUCTION PROJECT TEAM INTEGRATION

Communication, coordination, cooperation and collaboration are instrumental to support team integration in a construction project. However, each C concept has different characteristics compatible to specific hierarchies and dimensions of integration. Several cognitive judgements are presented in the discussion below.

4Cs Concept in Integration Hierarchy

Communication is the basis of interaction within a construction project team for task execution, control, information exchange and motivation that requires less collective means of outcomes. As may be seen from Table 1, this is consistent with the findings in other industries that ranked communication as the first and lowest level of integration. However, coordination involves more effort than communication because it requires collective outcomes aligned with project goals. The coordination process requires additional information processing that is important as a central mode of control among the distributed and collective tasks. Assignment of coordination as the second rank in the integration hierarchy is consistent with previous studies, except Badiru (2008).

Previous studies ranked cooperation in the hierarchy inconsistently. The differences lie on the perceived value of the contribution of cooperation knowledge to their subject of study. Those authors who perceive integration more in a relational oriented light are likely to rank cooperation at the highest level. This can be explained by their perceived relative importance of relational continuity with the purpose of strategic future planning, for example, in corporate business planning (Zamorrodian, 2011) and SCM topics (Lejune and Yakova, 2005). However, research subjects constrained by a temporary nature such as project based integration, are likely to rank collaboration as the highest level of integration. This is expected because projects normally involve professional teams which has its inherent set of diversities and capabilities. This fact is affirmed by Badiru (2008) who ranked the coordination higher than cooperation in project management.

In this study, collaboration is ranked the highest in the integration hierarchy above cooperation. This can still be linked to the current aspirations of IPD and collaborative BIM systems in the construction industry that signified the importance of joint efforts through sharing of diverse expertise, skills, and experience within construction project team.

4Cs Concept in Dimensions of Integration

As may be seen from Table 2, dimensions of integration, in general, can be classified into five: the degree of integration, the hierarchy level of management, the planning and decision-making, the form of relationship and the type of team structure. The associations between the 4Cs concept and the five dimensions are presented in Table 3 using a continuum framework.

According to 4Cs' ranking in integration hierarchy, a higher ranking of C concepts refers to a high degree of integration. This can be justified by the intensity of integration is more demanding to facilitate the collaboration through sharing of capabilities. It is followed by open negotiation for shared interest in cooperation and gradually reduced to the low degree of integration to enable the coordination and communication within the construction project team.

Table 3. 4Cs in five dimensions of integration

Hierarchy Rank	I (Communication)	II (Coordination)	III (Cooperation)	IV (Collaboration)
Degree of integration	Low - - - - - - - -		- - - - - High	
Management level	Operational - - - -		- - - - Strategical	
Planning and decision	Micro level - - - -		- - - Macro level	
Relationship	Contractual - - - -		-Trusted/Committed	
Team structure	Co-acting - - - - -		- - - - Integrated	

Higher ranking of C concepts involves managerial tasks in a strategic level. This is true when collaboration and cooperation are to be implemented through careful policy making by top management of different organisations involved in the construction project. In the same point of view, collaboration and cooperation tend to make strategic planning and decision through macro perspectives. However, coordination and communication can be exercised without much intervention from top management of the individual organisation. So that their managerial tasks are more applied at the operational level, and the planning and decisions are more related to the micro level of basic team interaction.

From relationship and team structure perspectives, higher ranking of C concepts tended to create trusted relationship under an integrated project team structure. This is because relational factors, such as affective trust, team cohesion and shared mental model are more demanding in both collaboration and cooperation. However, a contractual relationship under a co-acting project team structure is sufficient to lead the behaviour of coordination and communication in common project team interaction.

4CS FRAMEWORK IN CONSTRUCTION PROJECT TEAMS INTEGRATION

The 4Cs framework is developed with a purpose of providing a better picture of the overall discussion towards achieving the aim of this study. It is a full framework in an info-graphic format which is believed has the capability to convey the necessary information.

Figure 1 displayed the sequence of integration in construction project teamwork. The framework starts with communication, followed by coordination, then cooperation and finally collaboration. The lower ranking of C concept is a requisite to the higher ranking, but these higher rankings do not necessary co-exist when they are not demanded in the project team interaction. 4Cs complement each other to achieve particular teamwork.

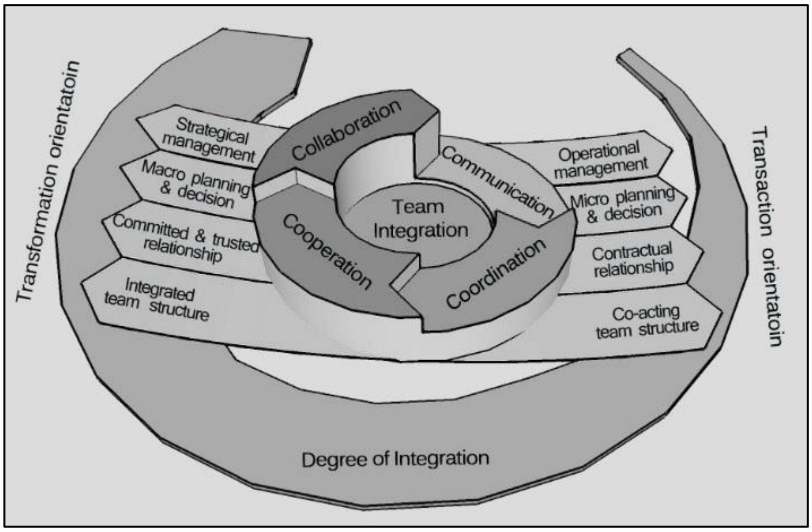

Figure 1. 4Cs Framework in Construction Project Team Integration

Communication and coordination are distinguishable from cooperation and collaboration based on two different transactional orientation and transformation orientation. Transactional orientation better captures the essences of communication and coordination for several reasons. Communication and coordination exist as the basic team interaction for task implementation, and both processes are fundamental to the integration initiative. Moreover, it spells out the exchange of information, i.e., communication, for the team to swiftly adjust the team's coordination level for integration purpose. This shows that both communication and coordination are prominent at the lower operational level of project management. Both processes involve the micro aspects of planning and decision-making for daily operations, achievable through activities such as corresponding email, site visit, site meeting, and other similar. Such a level of integration only requires a minimal commitment of contractual relationships but depends highly on the willingness of team members to work together harmoniously to achieve common goals. It is a mutually supporting unit which acts as a co-acting team to complete the project tasks. Therefore, its intensity of integration is perceived as lower than that required for cooperation and collaboration.

The transformative orientation is attributable to cooperation and collaboration due to several reasons. Cooperation and collaboration go beyond communication and coordination. Both processes are strategic concerns in the higher hierarchy of individual organisations within a project team. Careful policy making is required for both processes. It normally involves structural changes on team interaction, such as joint efforts, pooled resources, mutual risks taking and rewards sharing, shared governance structure and multi-parties' contractual arrangement. Comprehensive planning and decision are made in macro aspects for team integration success.

From relational aspects, both cooperation and collaboration work well when there is trust among project team members and authorities are vested in collaboration rather than concentrated on selected stakeholders. The project team is an integrated structure consistent to explore their diversity and capabilities to search for innovative solutions through mutual adaptation, learning, and co-specialised investments. All-in-all, cooperation and collaboration require a high level of integration.

CONCLUSIONS

Team integration is a major concern in construction, and it exploits operational synergies from the combined expertise, skills, and knowledge of the team members. Nevertheless, its benefits have yet to be optimised due to a myriad of challenges arising from unfamiliarity and lack of trust among team members working together for the first time. This paper has presented a new perspective of handling integration in construction project team by providing a framework alongside a new conceptualisation of 4Cs (Communication, Coordination, Cooperation and Collaboration). The discussion has been geared specifically towards the establishment of a framework that can showcase and explain the linkage between the 4Cs and team integration in construction projects. This newly conceptualised framework is hoped to inspire government agencies to pay more attention to communication, coordination, cooperation and collaboration when promoting integration in the construction industry, especially in governmental policy making. The industry players are also motivated to formulate integration strategies based on this new perspective that is believed to better match the operational requirements of daily team interaction. Lastly, scholars and researchers are welcome to debate the domains of team integration for continual exploration of innovative solutions to improve teamwork culture in the construction industry. This framework is not meant to be prescriptive and comprehensive rather it serves as an important insight into the benefits of integration when working in teams.

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FINANCING OPTIONS FOR ENERGY EFFICIENCY RETROFIT PROJECTS – A MALAYSIAN PERCEPTION

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Abstract
Since buildings consume a significant amount of energy, particularly for heating and cooling, and because existing buildings comprise the largest segment of the built environment, it is important to initiate energy conservation retrofits to reduce energy consumption and the cost of heating, cooling, and lighting buildings. A range of different financing options have surfaced to encourage such retrofits. This paper aims to explore the perception of practitioners regarding the different financing options available for retrofit projects. A semi-structured interview was conducted involving 16 experienced practitioners in Malaysia consisting of facility managers, architects and engineers. A majority of the interviewees indicate that the financial factor is key to influencing the decision to embark on a retrofit project. This includes not just cost savings as a result of the retrofit but also availability of governmental incentives. Among the key success factors identified are the need to look at retrofit as an integrated design rather than a silo-based approach, commitment from project teams, engagement with stakeholders and availability of governmental incentives. Based on the interviews, energy performance contracting (EPC) was seen as the preferred form of alternative financing due to its many advantages.

Keywords: *Financing options; alternative; retrofit projects; green buildings; governance*

INTRODUCTION

Sustainable development has been internationally agreed as a key goal for policy makers to guide development at global, national and local levels. The World Economic Forum identifies the building sector as an area which needs to be addressed as it accounts for “40% of the world’s energy use, 40% of carbon output and consumes 20% of available water” (Siew et al., 2013; Siew, 2014a). The increased recognition that buildings is a major contributor towards climate change puts constant pressure on construction practitioners to not just focus on traditional project goals of cost and time but also broader environmental and societal issues. This has also resulted in a strong shift towards the need to embed sustainability within the buildings and construction sector as evidenced by the plethora of research available in this area (see Claridge et al., 2016; Mickaityte et al., 2008; Siew, 2016; Siew et al., 2016; Siew, 2014b).

Roberts (2008) reports that the UK housing stock is replaced at a low rate about 1% a year, hence to halve UK’s greenhouse gas emissions by 2027 (Fleming, 2014), retrofitting old buildings is vital. A number of scholars have identified opportunities that exist for retrofitting buildings. Energy demand, for example, can be reduced through passive measures such as having retrofitted insulation, replacement of windows and proper airtightness while ensuring adequate ventilation (Mickaityte et al., 2008). Claridge et al. (2016) describe the progress of building operations and maintenance (O&M) in the last twenty years and argued that predicted retrofitted savings of up to 150% can be achieved when all O&M measures are fully implemented. Jaggs and Palmer (2000) develop the Energy Performance Indoor Environmental Quality Retrofit (EPIQR), a computer based programme which identifies the most appropriate refurbishment or retrofitting actions taking into account initial cost estimate. Tobias (2010) uses case study examples to explain some of the best practices and methods for retrofitting an existing office building to be green. Castleton et al. (2010) review the case for retrofitting existing buildings and found strong potential for green roof retrofits in the UK. Asadi et al. (2012) presents a multi-objective optimization model to assist stakeholders in selecting the most appropriate retrofitting measures aimed at minimizing energy use in buildings in a cost effective manner while satisfying occupant needs and requirements. Kumbaroğlu and Madlener (2012) introduce a techno-economic evaluation method for the energy retrofit of buildings. This method is geared towards finding an economically optimal set of retrofit measures.

According to Bateman (2012) the cost of deep retrofit is too high to be recovered. An independent research based on eight London-based projects found that each retrofit have cost in excess of £100,000. Hutchinson (2012) warns that the development and maintenance cost of bringing homes up to modern standards often exceeds their value which explains why councils faced with the need to manage their housing stock without subsidy are demolishing property where long term costs of ownership exceeds income generated.

While many have acknowledged that embedding sustainability into buildings will take trillions of dollars of investment and possibly challenging due to the fragmented nature of the building and construction sector (Siew, 2015); the fundamental question as to who will provide such funding remains. Various actors (project owners, investors and occupants) might have a tendency to perceive retrofit financing differently depending on their unique positions. This has given rise to a number of financing models in the market to cater for these different needs. This paper focuses on providing an overview of the different financing options that are available for the retrofit of building projects which has not been done before. Then, the findings from the interviews conducted to explore the Malaysian perception about these different financing options are shared. These findings will be of interest to both building and construction practitioners keen on exploring alternative financing options for their retrofit projects.

BACKGROUND

There are various types of funds available to finance retrofit projects and can generally be divided into either internal funding where the project is funded entirely using a company's own funds or external funding if sources of funding are from outside a company (Kamarudin et al., 2015). External funding can be further classified into either short (trade credit, blanket facility, overdraft), intermediate (leasing and mortgage) and long term (bonds, debentures, equity shares, on-bill financing, energy performance contracts and energy service agreements). A brief background on the nature and characteristics of these financing mechanisms are explored in this section. Table 1 describes some of the basic external financing mechanisms in the market.

Table 1. Basic external financing mechanisms

Financing Mechanism	Characteristic
Trade credit	Credit extended by one trader to another for the purchase of goods and services. This facilitates the purchase of supplies without immediate payment. The credit terms allowed by suppliers and subcontractors for which no cost is attached is typically on a short term basis (30-90 days).
Blanket facility	When a company's payment periods are too long, debts can be factored out to a finance company or commercial banks that provide such services. Cash received is equal to the debt amount factored out less the factoring charge at point of factoring.
Overdraft	This happens when a bank allows the request for an overdraft facility in a given sum. Funds can be withdrawn against the overdraft facility as and when required. However, there is a usually a maximum permissible withdrawal amount.
Bonds	Bonds are issued by large companies undertaking mega projects. They are repayable by a specific agreed time depending on when the bond matures (i.e. 5, 10 or 20 years) or they can be converted into equity shares at a pre-agreed time.
Debentures	These are long term loans secured by either the property for which the debenture was issued or on the overall company's property. This is done to raise funds from investors. In return, investors will receive regular interest payments (Drake, 2013). The risk is high, if the company is unable to repay the debenture by its due date, the debenture holders may seize the assets it has secured.

On-Bill Financing (OBF)

The federal government and many state governments in the United States have begun to encourage the adoption of OBF programmes by power and utility companies. OBF refers to a financial product that provide customers with financing to fund energy efficiency retrofits that are re-paid through customer's monthly utility bills. OBF removes the upfront cost barrier that traditionally inhibits customers from implementing vital energy efficiency retrofits. Eligible projects under OBF include retrofits such as the installation of (KPMG, 2012):

- Interior or exterior lighting retrofits
- Controls and energy management systems for heating, ventilation, and air-conditioning (HVAC)
- Solar panels
- High efficiency water cooled and air-cooled chillers replacements
- Boiler or furnace replacements
- Industrial fan replacements

Energy Service Agreements

Energy service agreements are similar to energy performance contracts in that a third-party company provides energy savings for a fee, the main difference being that the third party will pay the building's owners utility bill directly.

The model guarantees savings for an agreed upon period of time in exchange for set fees that are less than the borrower's utility bills (see Figure 1). Energy service agreement financing are off the balance sheets and is hence useful for tax purposes.

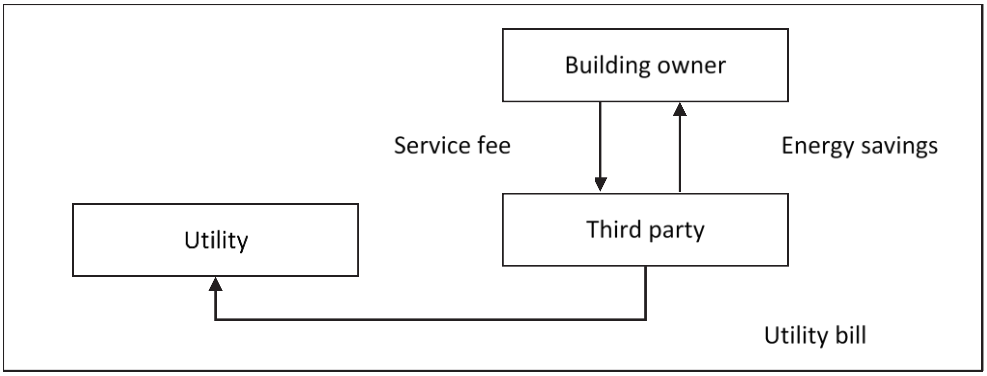

Figure 1. Energy Service Agreement model

For the energy service agreement, third party is paid only if savings are achieved and no creditworthiness test is necessary to evaluate the worth of the guaranteed savings. The service fees will take the place of the utility bill and can often be billed through to tenants. One of the challenges faced is that third parties have a tendency of looking only for large project sizes ($ >750,000) and the transaction costs can be high if each deal is heavily negotiated (US Department of Energy, 2016).

Energy Performance Contracting (EPC)

EPC provides customers with a comprehensive set of energy efficiency, renewable energy, and distributed generation measures often accompanied with guarantees that the savings produced by a project will be sufficient to finance the full cost of the project. According to a report by IFC International (2007), by dollar volume in the US market place, ESCO projects are largely focused energy efficiency (73%), renewables (10%) while the remaining constitute combined heat and power as well as consulting and planning services (17%). The drivers for EPC include: (i) savings mandates where both federal and state governments are becoming increasingly aggressive about energy savings goals for public facilities but not providing capital budgets to pay for energy efficiency improvements; (ii) green buildings landscape where facility owners who are keen on 'greening' their buildings often implement EPC projects, (iii) climate change where energy efficiency is the first choice of organisations trying to meet state mandates for greenhouse gas reductions; and (iv) utility needs where state regulators faced with utility applications to build new generation of power plants are increasingly looking to large-scale energy efficiency programs as an alternative. EPC, which can be self-financed through energy savings is seen as an attractive option.

The main elements of EPC are (ICF International, 2007):

- Turnkey service – ESCO provides all of the services required to design and implement a comprehensive project at the customer facility, from the initial energy audit to long term monitoring and verification of project savings

- Comprehensive measures – The ESCO tailors a comprehensive set of measures to fit the needs of a particular facility, and can include energy efficiency, renewables, distributed generation, water conservation, and sustainable materials and operations

- Project financing – The ESCO arranges for long term project financing that is provided by a third-party financing company. Financing is typically in the form of an operating or municipal lease

There are two major types of contracting models namely:

i) Shared savings – cost savings are split for a pre-determine length of time in accordance with a pre-arranged percentage. There is no standard 'split' as this depends on the cost of the project, the length of the contract and the risks taken by ESCO and the consumer.

ii) Guaranteed savings – ESCO guarantees a certain level of energy savings and in this way shields the client from any performance risk

A comparison between these two types of contracting models are summarized in Table 2.

Criteria	Guaranteed savings	Shared savings
Performance	Related to the energy level saved	Related to the cost of energy saved, ESCO bills upon receiving actual results
Performance and credit risk	ESCO carried performance risk. Energy-user carried credit risk	ESCO carried both performance and credit risk as it typically carries out the financing
Value	Value of energy saved is guaranteed to meet debt service obligations down to a floor price	Value of payments to ESCO is linked to energy price; betting on price of energy can be risky
Creditworthiness	Requires creditworthy customer	Can serve customers that do not have access to financing
Monitoring and verification	Extensive	Equipment may be leased
Leverage	ESCO can do more projects without getting highly leveraged	Favours large ESCO; small ESCOs become too leveraged to do more projects

Table 2. Comparison between guaranteed and shared savings (Institute for Energy and Transport, 2016)

Property Assessed Clean Energy (PACE)

PACE financing models address many of the challenges faced by ESA and EPC. It is a solution to the first cost-hurdle that allows local governments to use their traditional assessment or improvement district authority to provide property owners with up-front capital for energy efficiency projects. The capital investment is then repaid through assessments levied on property that benefits from these improvements. The property assessments are secured by a lien that ranks senior to a mortgage lien. With PACE, even if the owner sells off the property, the lien remains on the property. PACE allows for a kind of standardized assets that are more heavily securitized and if large volumes are aggregated, larger pools of financing can be made possible through securitization. There are four basic financing models in PACE:

Municipal bonds

- Municipal bond funded available on demand – PACE authority uses an unallocated reserve pool to finance projects as soon as applications are processed and work is completed. Revenue bonds will be issued to replenish the reserve pool. This model makes funds available on demand and with a long term interest rate can be determined.

- Municipal bond funded, available as sufficient project volumes can be pooled for a bond issuance-PACE authority waits to aggregate a sufficient dollar amount of projects so that a bond issuance makes sense. Once the sufficient volume is reached, a municipal revenue bond sale is arranged. The advantage of this approach lies in the volume of transaction, which potentially leads to a lower interest rate. One disadvantage is that projects have to wait from the time of application and approval until the time of the bond issuance to proceed.

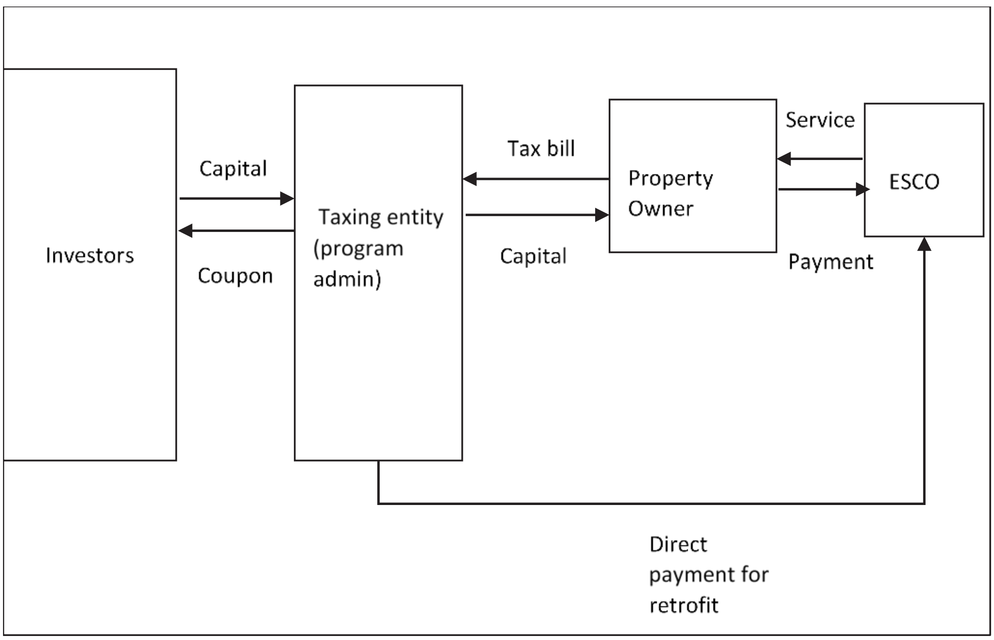

Figure 2. Municipal bond funded PACE transaction

Privately funded model

- Open-market/ owner arranged programs, funded individually- projects are financed individually through a capital provider of choice, municipal bonds, or a combination of the two. Programs pair each PACE project with a prospective funder, selected through a competitive bidding process or as part of a financing solution offered by a contractor/installer

- Turnkey financing programs, funding on demand- these programs have one private financing option that is arranged by the program's administrator. This provides easy access to funding, on demand, at attractive rates negotiated on the basis of scaled projections.

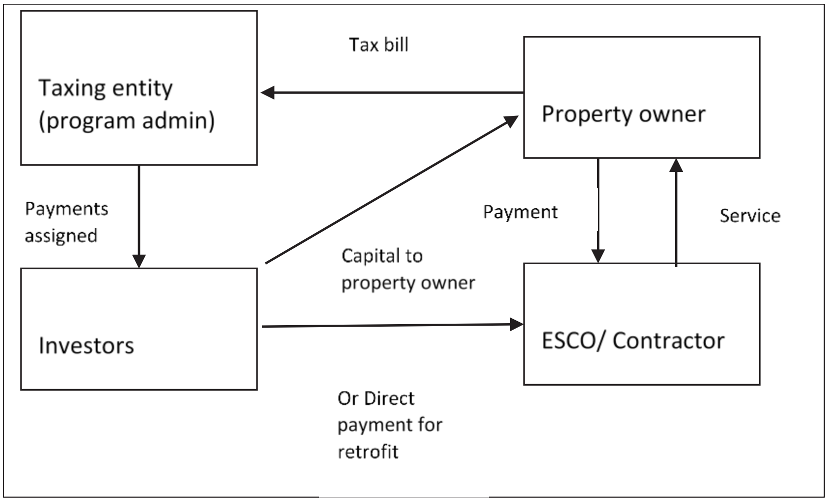

Figure 3. Privately funded PACE transaction

The aforementioned energy efficiency finance models are compared in Table 3 (Kim et al., 2012).

Table 3. Comparison between different energy efficiency finance models

Financing model	EPC	ESA	PACE
Market penetration	High for Municipal, University, Schools and Hospital (MUSH), low for commercial and industrial	Low	Low
Target market	MUSH, Commercial and residential	MUSH, Commercial and residential	Residential and commercial
Balance sheet	On or Off	On or Off	Undetermined
Typical project size	Unlimited	$250,000 to $10 million	$2,000 to $2.5 million
Allows for extensive retrofits	Yes	Yes	Yes
Repayment method	Energy savings	Energy savings	Property assessments
Security/Collateral	Depends on financing (i.e. lease or debt)	Equipment	Assessment lien
Responsibility of utility bills	ESCO or customer	Customer	Customer

Table A1 (Appendix) summarises some of the major funding provided by governments worldwide.

METHODOLOGY

Participants were carefully selected based on their experience in the field, position within the company and their willingness to be interviewed. The interviews were administered by both telephone and face-to-face meetings. These interviews lasted between 40-55 minutes each. A total of 16 interviews were completed in the city of Kuala Lumpur, Malaysia. Table 4 shows the job title, sectoral experience and educational background of the participants.

From the table, it is observed that an overwhelming majority of participants have a facilities management background followed by those with an architectural background and engineers. More than half of the participants (55%) have a sectoral experience between 5 to 20 years while the remaining (45%) have more than 20 years of experience in the sector.

Table 4. Background of Participants

Characteristics	Participants
Occupation	
Facilities manager	7
Architect	6
Engineers	3
Education	
Graduate	13
PhD	3
Position in the firm	
Firm Owner	5
Project Manager	9
General Coordinator	2
Sector experience	
5-10	3
11-20	8
>20	5

A semi-structured interview approach was adopted in this study to elicit information from participants. The semi-structured interviews unfolded in a conversational manner which allows for participants to explore issues in depth (Longhurst, 2010). This was done through two focus groups in Malaysia consisting of 3 participants each for the pilot interview. The pilot interview was conducted to ensure that the questions were interpreted in a manner that is consistent with the intent of the interviewer. Based on the pilot interviews, the research questions were revised as follows:

Research Questions

1. What are some of the factors considered when deciding whether to embark on a retrofit project?
2. What are some of the key success factors or barriers towards ensuring the success of a retrofit project?
3. Which of the financing mechanism is preferred when it comes to retrofitting projects and why?
4. Do you feel that the government provides adequate incentives for retrofit projects? If not, what can be done to improve?

DISCUSSION

1. What are some of the factors considered when deciding whether to embark on a retrofit project?

A majority of the participants indicated that the financial factor is key to influencing the decision to embark on a retrofit project. This includes not just cost savings as a result of the retrofit but also availability of governmental incentives. This further reinforces the finding by Lockwood (2009) where many markets are still lagging behind in green retrofits possibly because of the cost factor. Those who are aggressively driving green retrofits are either Fortune 500 multinational corporations with corporate sustainability reports or new companies that are interested in recruiting cutting-edge young talent sees sustainability as a given not an add-on.

"The most important criterion is how long the payback period will be. We will do a cost benefit analysis and decide whether this is an investment that the company is willing to take. Of course, we will also consider if there are incentives available from the government. A secondary reason is the environmental benefits that is how much of reduced energy demand that would come as a result of such a retrofit."

"It is important to quantify the value of a retrofit be it from a monetary perspective or energy savings generated as a result of the retrofit. If savings is minimal there is really no point embarking on a retrofit project."

2. What are some of the key success factors towards ensuring the success of a retrofit project?

There are a number of success factors identified by the interviewees. This includes the need to look at retrofit as an integrated design rather than a silo-based approach. The overall examination of a building should include its full system operations as well as building occupant's energy needs. This may involve technical audits such as observing the building envelope's thermal performance, equipment monitoring and building occupant survey. An integrated approach ensures that every action plan taken reinforces each other.

Also commitment from project teams as well as engagement with stakeholders is viewed as pivotal. This is needed so that every party is clear about their roles and responsibilities in the retrofit project. Lastly, governmental incentives or green funding was highlighted as a key success factor especially in lieu of the fact that some of the cost of retrofit installation is exorbitant especially among smaller companies.

"Following a silo-based approach is common in retrofits. At present, energy audits in a building is performed in a disintegrated fashion where specialty contractors will assess either one or two systems and ignore the rest and the project only tackles a few system upgrades. Typically, energy efficiency assessments look primarily at lightings and solutions are proposed for the most efficient lighting programme. It includes an assessment of HVAC (heating, ventilation and air-conditioning) pumps and motors and down the list. If you want to succeed you must look into an integrated design. With an integrated design, you not only evaluate the systems but also part of an overall energy consumption picture to ensure that every action reinforces each other. Another success factor is commitment from the project teams that are involved in the installation process/ retrofits. There needs to be sufficient follow through and effort in monitoring and reporting of results."

"For us, a key success factor is to ensure that every stakeholder involved in the installation understand their roles and responsibilities. Ownership is absolutely key. There needs to be clear timelines set out as well with key milestones laid out. Tone from the top and commitment

from senior management is vital to ensure the success of retrofits. Governmental incentives are also important especially if the cost of installation is high, the case usually."

"Energy retrofits are really costly. Hence, support from governments especially in the form of incentives will go a long way to help justify the cost of these retrofits. For a small company like ours, it becomes much easier for us to scale our impact."

3. Which of the financing mechanism is preferred when it comes to retrofitting projects and why?

From the interviews conducted, energy performance contracting appears to be the most preferred option for financing retrofit projects. Among some of the reasons cited are simply that energy service company providers usually take up any underperformance risk as a result of the retrofits. As well, some respondents claim that they may not have the expertise or even resources to conduct full energy audits.

"We opt for energy performance contracting (EPC) in our retrofit projects especially the guaranteed savings model. Our management has a lower risk appetite. For this model, any underperformance risk is taken up by the energy service company provider (ESCO).

"In an ideal situation, we would prefer to finance any retrofits internally. However, as you are aware the cost of energy retrofits can be really expensive and also another issue is we do not have sufficient resources to conduct full energy audits. Therefore, energy performance contracting (EPC) is preferred because ESCOs will handle most of these audits, provide recommendations/ solutions and handle the financing.

"Energy performance contracting is very popular these days. The number of vendors that provide such services have increased over the past decade. We feel that this is an innovative form of financing and very convenient for building owners."

Based on the interviews, many have pointed out that internal financing is really difficult to carry out as it requires a company to have really strong balance sheets and healthy cash flows. While the number of loan financing for retrofits provided by banking institutions have increased over the years, yet many project owners are hesitant to apply for such financing due to the high interest rates. On the flip side, the strength of internal financing is that any savings that have occurred as a result of a retrofit will be retained completely by the owner.

"Internal financing requires the building/ project manager to have strong balance sheets and cash flows. Often, this can be a barrier to retrofit installations. The advantage of internal financing is that savings occurred will be retained by the owner. The issue with taking loans from banks is that the interest rates may be really high."

"In Malaysia, energy efficiency retrofits of buildings are not widespread. Those who typically engage in such retrofits are usually large corporations who have strong cash flows and are able to fund such retrofits internally".

4. Do you feel that the government provides adequate incentives for retrofit projects? If not, what can be done to improve?

It is recognised that energy supply and use issues in Malaysia largely resides under the federal jurisdiction and that there are subsidies such as tax exemptions that encourage reduction of energy use. In Malaysia, funding allocation for retrofits is largely available for historical buildings under the National Heritage Act 2005 and not so much for residential or commercial buildings as reflected in the interviews.

"In Malaysia, the jurisdiction on energy supply and use is vested with the Federal Government. The Federal Government formulates and implements energy policies including energy efficiency policies. Based on the current setup, energy issues are handled mainly by the Economic Planning Unit of Prime Minister's Department (EPU), the Ministry of Energy, Green Technology and Water (MEGTW) and the Energy Commission (EC). The EPU decides macro energy policies including energy subsidies, energy market structure, and energy infrastructure development.

"In Australia, the Green Building Fund (GBF) is provided for retrofits that have high potential for reduction of greenhouse gases in commercial buildings. The situation in Malaysia, however, is slightly different compared to other more advanced countries. If the retrofit involves historical buildings, then under the National Heritage Act 2005, the federal government will provide grants for the preservation works, otherwise such funds for retrofitting for residential or commercial buildings do not come by easily to the best of my knowledge."

A majority of interviewees still felt that the Malaysian government can do a lot more in the provision of funds for energy efficiency retrofits. An interviewee pointed out that the government seems to be changing their strategy by embarking on a more regulatory (or forced) approach which might not be beneficial in the long run especially for smaller private building owners. At present, current funding seems to come from other external or international agencies such as the Danish Energy Management (DEM) in collaboration with the Danish Climate Investment Fund.

"The government is currently changing its strategy by embarking on more of a regulatory approach. I am not sure if this move is beneficial in the long run for smaller private building owners. Well, it really depends on the cost-benefit analysis at the end of the day to justify whether a retrofit is worth pursuing."

"Tax exemptions to promote the reduction of energy use is available but very limited subsidies are available for retrofits. The Malaysian government can certainly do more in providing such funds to further encourage building owners to embark on energy efficiency retrofits. The Danish Energy Management (DEM) has worked in collaboration with the Danish Climate Investment Fund to invest, finance and implement retrofitting projects in Melaka (one of the states in Malaysia) under the Energy Performance Contract."

CONCLUSION

This study has explored the Malaysian perception of financing options for retrofit projects. First, a literature survey was conducted to identify the characteristics of both internal and external funding mechanisms which can be further subdivided into: i) short term financing (i.e. trade credit, blanket facility, overdraft; ii) intermediate financing (i.e. leasing and mortgage) and iii) long term financing (i.e. bonds, debentures, equity shares, on-bill financing, energy performance contracts and energy service agreements). A semi-structured interview was conducted with 16 experienced professionals either by telephone or face-to-face meetings. The findings from the interviews revealed that financial factor is key to influencing the decision to embark on a retrofit project. This includes not just cost savings as a result of the retrofit but also availability of governmental incentives. The following have been identified as key success factors for a retrofit project: the need to look at retrofit as an integrated design rather than a silo-based approach; commitment from project teams; engagement with stakeholders; and availability of governmental incentives. A majority of participants felt that the Malaysian government could do more in terms of providing funding to support energy efficiency retrofits. As well, a number of interviewees highlighted their preference for energy performance contracting (EPC) as an alternative means of financing due to its many advantages.

Future research: The nature of this study is exploratory in order to gauge the perception of Malaysian practitioners on building retrofit projects. Interviews were hence selected as part of the research design. Currently, the scope of this study is only among Malaysian practitioners, it would be really interesting to explore if perception differs for practitioners from other countries given their unique circumstances. During the interview, it was highlighted that the Malaysian government is moving towards a more regulatory approach when it comes to energy efficiency retrofits, it might be worth exploring as well in further depth as to why the government has decided on such a move and what are the perceived benefits of mandating this. This perhaps can also be contrasted against the decision by the Hong Kong government which has mandated that all new buildings should adhere to HK-BEAM, a green rating tool which serves to assess the sustainability of buildings (see Siew et al., 2013).

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APPENDIX A

Table A1. Comparative analysis of different government grants

Green Funding	Country	Owners	Aim	Value of grant	Criteria
Funding opportunity announcement (FOA)	US	US Department of Energy	Provides funding for the implementation of different energy efficiency programmes	$548K to $1.8 million	Scientific and technological merit
Green Deal Plan	UK	Department of Energy and Climate Change	Enables the offering of energy efficient improvements to customers at no upfront cost	No upfront cost but Green Deal charge is collected	Expected financial savings to be greater or at least equal to the costs attached Measures installed must be based on an accredited installer
Green Building Fund	Australia	Department of Innovation, Industry, Science and Research	Provides funding to building owners who are able to demonstrate potential in reducing greenhouse gas emissions (commercial buildings)	AUD 50,000-500,000	• Potential for greenhouse gas emission • Demonstration of potential Project design and management
Renewable Heat Incentive (RHI)	UK	Department of Energy and Climate Change	Provides long term support for the installation of renewable heat energy technologies like heat pumps, biomass boilers	Cap at $70 million	Agreement from household to monitor the performance of installations A well-insulated home based on its Energy Performance Certificate

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GUIDE TO AUTHORS

Aims and Scope:

The Malaysian Construction Research Journal (MCRJ) is the journal dedicated to the documentation of R&D achievements and technological development relevant to the construction industry within Malaysia and elsewhere in the world. It is a collation of research papers and other academic publications produced by researchers, practitioners, industrialists, academicians, and all those involved in the construction industry. The papers cover a wide spectrum encompassing building technology, materials science, information technology, environment, quality, economics and many relevant disciplines that can contribute to the enhancement of knowledge in the construction field. The MCRJ aspire to become the premier communication media amongst knowledge professionals in the construction industry and shall hopefully, breach the knowledge gap currently prevalent between and amongst the knowledge producers and the construction practitioners.

Articles submitted will be reviewed and accepted on the understanding that they have not been published elsewhere. The authors have to fill the Declaration of the Authors form and return the form via fax to the secretariat. The length of articles should be between 3,500 and 8,000 words or approximately 8 – 15 printed pages (final version). The manuscripts should be written in English. The original manuscript should be typed one sided, single-spacing, single column with font of 11 point (Times New Roman). Paper size should be of Executive (18.42 cm x 26.67 cm) with 2 cm margins on the left, right and bottom and 3 cm for the top. Authors can submit the manuscript:

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CODIFICATION AND APPLICATION OF SEMI-LOOF ELEMENTS FOR COMPLEX STRUCTURES

Ahmad Abd Rahman[1,2], Maria Diyana Musa[2] and Sumiana Yusoff[2]
[1]*Department of Quantity Surveying, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Sarawak, Malaysia*
[2] *Institute of Ocean and Earth Sciences (IOES), University of Malaya, Malaysia*

Abstract (Arial Bold, 9pt. Left and right indent 0.64 cm.)
Damage assessment …… ……(it should be single paragraph of about 100 – 250 words.)

Keywords: *Finite element analysis; Modal analysis; Mode shape; Natural frequency; Plate structure*

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Body Text: Times New Roman, 11 pt. All paragraph must be differentiate by 0.64 cm tab.

Units: All units and abbreviations of dimensions should conform to SI standards.

Figures: Figures should be in box with line width 0.5pt. All illustrations and photographs must be numbered consecutively as it appears in the text and accompanied with appropriate captions below them.

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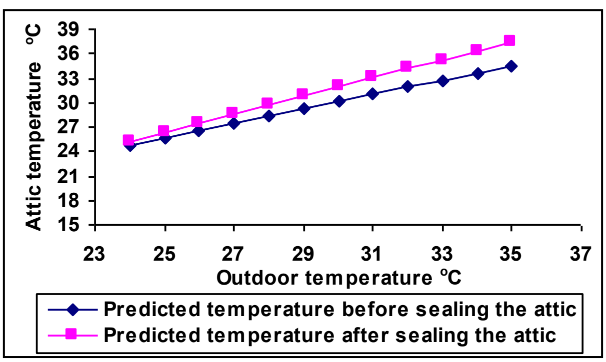

Figure 8. Computed attic temperature with sealed and ventilated attic

Tables: Arial, 8pt. Table should be incorporated in the text.

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Table Line: 0.5pt.

Table 1. Recommended/Acceptable Physical water quality criteria

Parameter	Raw Water Quality	Drinking Water Quality
Total coliform (MPN/100ml)	500	0
Turbidity (NTU)	1000	5
Color (Hazen)	300	15
pH	5.5-9.0	6.5-9.0

(Source: Twort et al., 1985; MWA,1994)

Reference: Times New Roman, 11pt. Left indent 0.64 cm, first line left indent – 0.64 cm. **Reference should be cited in the text as follows:** "Berdahl and Bretz (1997) found…" or "(Bower et al., 1998)". References should be listed in alphabetical order, on separate sheets from the text. In the list of References, the titles of periodicals should be given in full, while for books should state the title, place of publication, name of publisher, and indication of edition.

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