IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Investigation on dynamic performance of concrete column crumb rubber steel and fiber concrete

To cite this article: M Z Siti Nurul Nureda *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **271** 012082

Investigation on dynamic performance of concrete column crumb rubber steel and fiber concrete

M Z Siti Nurul Nureda[1],A K Mariyana[1],M Iqbal Khiyon[1],M S Abdul Rahman[1]and Z Nurizaty[1]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.
Corresponding author: snnureda2@live.utm.my

Abstract. In general the Normal Concrete (NC) are by quasi-brittle failure, where, the nearly complete loss of loading capacity, once failure is initiated especially under dynamic loadings. The significance of this study is to improve the damping properties of concrete structure by utilization of the recycled materials from waste tires to be used in concrete as structural materials that improve seismic performance. In this study, the concrete containing 10% of fine crumb rubber and 1 % volume fraction of steel fiber from waste tires is use to investigate the dynamic performance (natural frequency and damping ratio).A small scale column were fabricated from Treated Crumb Rubber and Steel Fiber Concrete (TCRSFC) and NC were cast and cured for 28 days to investigate the dynamic performance. Based on analysis, dynamic modulus, damping ratio and natural frequency of TCRSFC has improved considerably by 5.18%, 109% and 10.94% when compared with NC. The TCRSFC producing concrete with the desired properties as well as to introduce the huge potential as dynamic resistance structure from severe damage especially prevention on catastrophic failure.

1. Introduction
Concreteis a composite material, consisting of Portland cement, aggregates and water. This material has been utilized as construction materials since 1824. Characteristic of the concrete depends on the aggregates or cement used in the mixture. Now a days, there are many innovation has be initiating to improve the characteristic of the concrete. One of the ongoing research is concrete properties can be modified to perform in a more ductile manner by replacing fine aggregates using crumb rubber and the addition of randomly distributed discrete fibers in the concrete matrix, which prevent and limit initiation, propagation and integrate of cracks. Therefore, many researchers have been carried out extensive studies on the utilization of the crumb rubber and steel fiber derived from waste tires into concrete mixes. The introduction of steel reinforcement in concrete structure has proved its improvement in tensile strength but when exposing to dynamic loading such as earthquake event, it is cause severe damage due to less energy dissipation [1]. Previous research has shown that the utilization of crumb rubber has improve its damping ratio which is low in seismic response but give reduction in compressive strength and elastic modulus [1 – 3].It is suggested that the replacement of crumb rubber in range of 0%-20% by aggregate replacement [4,5]. The reduction in compressive strength can be tackle by modification in water cement ratio [6 – 8]. Therefore, the problematic reduction in strength with inclusion of crumb rubber can be improved by modification in water cement

ratio. Besides, the addition of steel fiber from waste tire will helps in improving the concrete properties. Based on past studies, the inclusion of steel fiber in concrete mixtures improve the tensile capacity, toughness and reduce surface cracking and it is suggested that the addition is in range of 0.5%-2.5% [9]. Meanwhile, production of waste tire is one of the main problem faced by most of the country all over the world [10 – 12]. These production cause a lot of environmental pollution especially when stored in landfills or stockpile [13]. Besides, burning activities of waste tires causes health hazard from excessive smoke and toxic during burning process [14,15].

In this research, the mechanical and dynamic property of concrete has been investigated and compared with those derived given Treated Crumb Rubber Steel Fiber Concrete (TCRSFC) and Normal Concrete (NC).The optimum replacement of crumb rubber and of steel fiber was examined. The effect of combination between crumb rubber with steel fiber with at the replacement ratios obtained, modified water cement ratio on the mechanical and dynamic properties of concrete column is determined as well.

2.Materials and test methods

2.1.Materials

All concrete mixtures in the test are using a same binder materials which is Ordinary Portland Cement (OPC) which is design for concrete grade 30. Fine aggregates and crumb rubber used in concrete mixture is passing through 4.75mm with specific gravity of 2.60 and 1.21 while maximum size of coarse aggregates is 10mm. Crumb rubber was treated with Sodium Hydroxide (NaOH) solution for 20 minutes for removing unnecessary impurities on crumb rubber surface. Then, crumb rubber was rinsed with water and drying for 24 hours at ambient temperature. Meanwhile, the average length of steel fiber is 2.35cm, diameter of 0.30mm with tensile strength and tensile strength of 897 MPa were used in the mixture. Figure 1 shows the (a) crumb rubber and (b) steel fiber used in concrete mixtures.

(a)

(b)

Figure 1. (a) Crumb rubber and (b) Steel fiber.

2.2.Mix design

There are two types of concrete mixtures that have been used in this research with different mix proportions. The design was done according to Building Research Establishment:1988[16]. Treated Crumb Rubber Steel Fiber Concrete (TCRSFC) (0.50 water cement ratio) were using lower water cement ratio compared to Normal Concrete (NC) (0.55 water cement ratio) because previous studies has shown that concrete mixtures exhibits significant strength reduction when using same water cement ratio [1, 2] .Table 1 denotes the mix proportion for concrete specimen.

Table 1. Mix design of concrete specimen.

	C, (kg/m^3)	W, (kg/m^3)	FA, (kg/m^3)	CA, (kg/m^3)	W/C	CR, (%)	CR, (kg/m^3)	SF (1%)	SF, (kg/m^3)	SP (%)
NC	425	233	750	661	0.55	-	-	-	-	-
TCRFC	466	233	920	897	0.50	10	75	1.0	53.40	1.0

Note: C: Cement, W: Water, FA: Fine Aggregate, CA: Coarse Aggregate, W/C: Water/Cement ratio, CR: Crumb Rubber, SF: Steel Fiber, SP: Super plasticizer

2.3.Fabrication of column specimen

Column specimen consist of three parts, lump mass, column, and foundation, that were fabricated by using plywood and column specimen consist of two reinforcement bars that have 500 N/mm^2 characteristic strength, fy. The diameter (d) of reinforcement bar is 3 mm with length of 724 mm. The curtailment of reinforcement at lump mass is one-quarter of column length and the anchor is 5d from reinforcement which is designed according to BS EN 1992-1-1 (2004)[17].

3.Sample preparation

Modulus of elasticity test are determined according to BS 1881-121:1983 [18].Normal Concrete (NC) and Treated Crumb Rubber Steel Fiber Concrete (TCRSFC) mixture were cast for six cylinders with 100 mm diameter and 200 mm height (modulus of elasticity)and small scale column with two reinforcement (3mm diameter) which is designed by 1:6 ratio according to Malaysian Standard MS1064: Part 10: 2001 [19]. There are three parts for small scale column which is lump mass (120mm×120mm×190mm), column (40mm×40mm×500mm) and foundation (275mm×275mm×80mm). Small scale column was fixed with bolts and nuts on shaking table and accelerometer was glued on lump mass, column and shaking table before being tested under free vibration and seismic test as shown in figure 2.

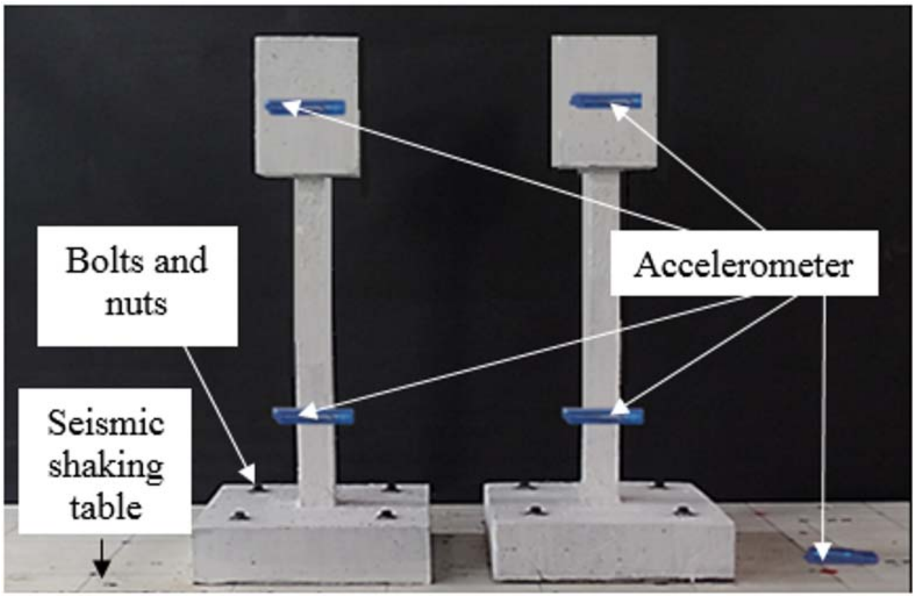


Figure 2. Illustration of small scale column fixed on shaking table.

For free vibration test, an impact load was applied at lump mass by a hammer with 2.439 kg to induce the vibration, and the vibration was recorded by accelerometer. After free vibration test, column specimen was tested by exiting the shaking table test with modified north-south Ranau earthquake ground motion which is 1.0g. The ground motion was scale up from 0.126g (6.1 magnitude) to 1.0g in order to examine the effectiveness of combination 10% crumb rubber and 1% steel fiber in concrete column (TCRSFC) during earthquake event.

4.Results and discussion

4.1.Modulus of elasticity

The modulus of elasticity for both Normal Concrete (NC) and Treated Crumb Rubber Steel Fiber Concrete (TCRSFC) was tested and determined by using British Standards 1881-Part 121[18] which is defined as secant modulus (A) at one-third of compressive strength cube at age 28 days. Meanwhile the dynamic modulus (B) is defined as small instantaneous strain. Generally, the dynamic modulus is 20%-40% higher than secant modulus. Besides, dynamic modulus are more suitable for stress analysis of structure that subjected to earthquake or impact loading[20]. Figure 3 illustrate the stress-strain curve from tested specimen.

Based on analysis, secant modulus, Es and dynamic modulus, E_D of TCRSFC cylinder shows an increment by 5.60% (27.82 GPa) and 5.18% (31.05GPa)NC cylinder which is 26.28 GPa and 29.52 GPa. Figure 4 shows the mode of failure for concrete specimen under modulus of elasticity. Based on observation, NC exhibited a brittle failure which is small pieces of concrete are shattered meanwhile TCRSFC are more ductile and less brittle because it was confined by 1% of steel fiber in concrete specimen thus improve the modulus of elasticity.

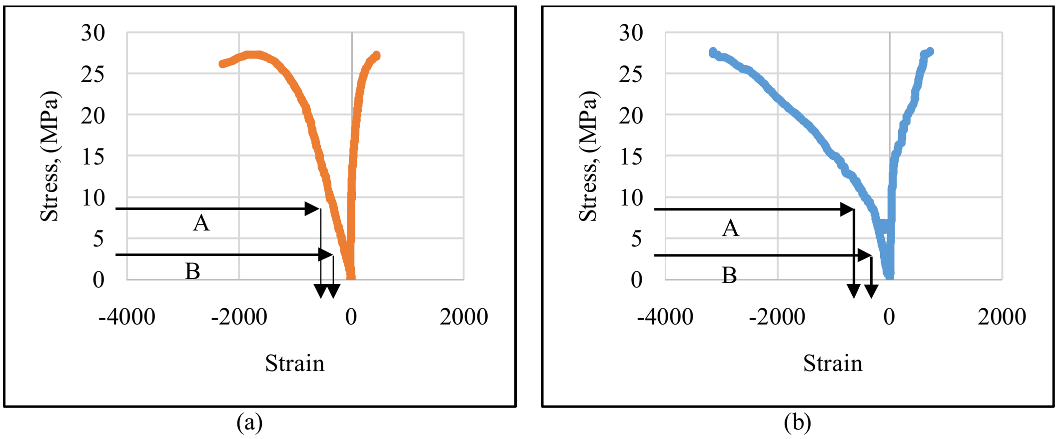


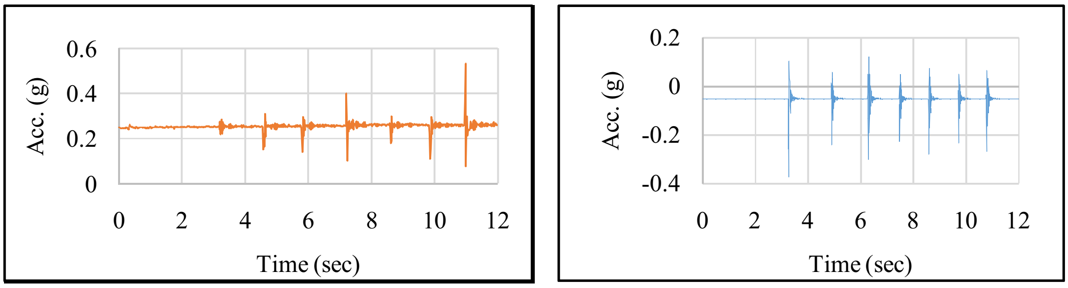
Figure 3. Stress-strain curve of (a) Normal Concrete (NC) and (b) Stress-strain of Treated Crumb Rubber Steel Fiber Concrete (TCRSFC), A is secant modulus and B is dynamic modulus.

(a) (b)

Figure 4. Mode of failure for (a) Normal Concrete (NC) and (b) Treated Crumb Rubber Steel Fiber Concrete (TCRSFC).

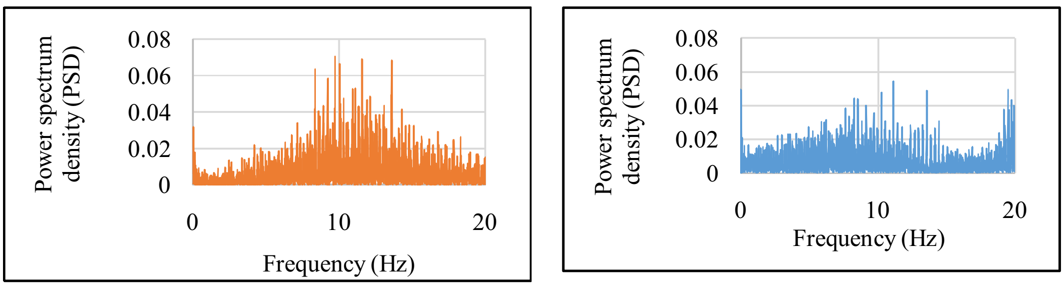
4.2. Free vibration test

Damping ratio is defined as energy dissipation which mean can be measured by free vibration test. Four concrete column consist of two Normal Concrete (NC) and Treated Crumb Rubber Steel Fiber Concrete (TCRSFC) was tested under free vibration test. Figure 5 and 6 shows the Time-History and Power Spectrum Distribution (PSD) that was extract from free vibration test.



(a) (b)

Figure 5. Free vibration decay Time-History of (a) Normal Concrete (NC) and (b) Treated Crumb Rubber Steel Fiber Concrete (TCRSFC).



(a) (b)

Figure 6. Power Spectrum Distribution of (a) Normal Concrete (NC) and (b) Treated Crumb Rubber Steel Fiber Concrete (TCRSFC).

Damping ratio was computed by using logarithm decrement equation (1), which A1 denotes as the first amplitude of acceleration, an is the amplitude after next cycle and n is next cycle of oscillation.

$$\text{Damping, } \zeta = {}^{1}\!/_{2n\pi} \text{ x In } {}^{A1}\!/_{An} \quad (1)$$

Meanwhile, the natural frequency was determined from PSD curve. Table 2 denotes the value of damping ratio and natural frequency for NC and TCRSFC. Based on analysis, TCRSFC give 109% increment in damping ratio, where is the damping ratio for TCRSFC give 9.6% with respect to NC with 4.6%. According to the past research, the range of damping ratio for concrete are varied from 4%-7% [1]. Meanwhile, the natural frequency of TCRSFC has increase by 10.96% (11.14 Hz) compared with NC (10.04Hz). According to resonance method, the natural frequency is directly proportional to dynamic modulus, E_D [21]. Therefore, TCRSCFC column has the highest in natural frequency as compared to NC due to the highest in stiffness (dynamic modulus).

Table 2. Damping ratio and natural frequency of Normal Concrete (NC) and Treated Crumb Rubber Steel Fiber Concrete (TCRSFC).

	NC	TCRSFC
Mass (kg)	21.60	22.60
Percentage different (%)	-	+4.60
Amplitude, (A1)	0.5341	0.3735
Amplitude, (An)	0.2987	0.1111
Damping, ζ (%)	4.6	9.6
Percentage different (%)	-	+109
Natural frequency (Hz)	10.04	11.14
Percentage different (%)	-	+10.96

4.3.Seismic shaking table test

By using the same column specimen, seismic shaking table were tested after free vibration test. Figure 7 shows the crack on column specimen surface after exited with North-South Ranau earthquake 1.0g ground motion. Based on observation, the crack lines on Normal Concrete (NC) and Treated Crumb Rubber Concrete (TCRSFC) appear at connection between foundation and column, and at the column surface but crack on TCRSFC relatively fewer than NC as shown in figure 7.

(a) (b)

Figure 7. Damage of column specimen after seismic shaking table test. (a) Normal Concrete (NC)(b) Treated Crumb Rubber Concrete (TCRSFC).

The response of acceleration was recorded by accelerometer and the result was plotted as a Time-History graph. Figure 8 (a) shows the input of 1.0g ground motion while figure 8 (b) shows the response of acceleration on column specimen. Based on analysis, the seismic response of TCRSFC column demonstrated smaller acceleration response which is 1.21g as compared to NC column (1.91g). Smaller acceleration response on TCRSFC is due to inclusion of 10% treated crumb rubber and 1% of steel fiber because crumb rubber itself has high resistance in impact loading while steel fiber improved the concrete stiffness [1, 22] which is proved by an improvement in dynamic modulus and damping ratio. On average, the inclusion of 10% treated crumb rubber and 1% steel fiber in concrete mixtures reduce the acceleration response approximately 36%.

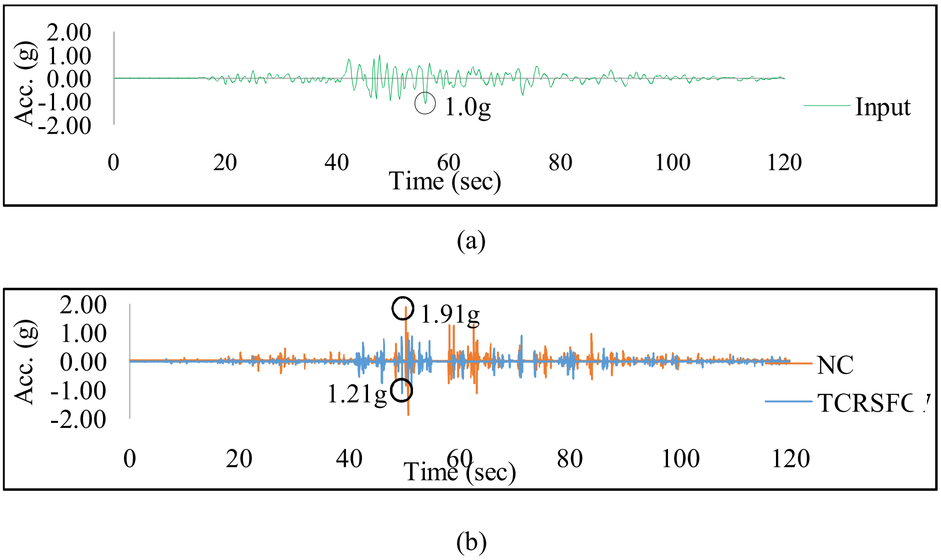


Figure 8.(a) Seismic input and (b) seismic response for column specimen.

5.Conclusions

This research focused on investigation of dynamic performance of concrete with inclusion of 10% crumb rubber as sand replacement and 1% of steel fiber as addition in concrete. The conclusion are presumed:

(a) Dynamic modulus for Treated Crumb Rubber Steel Fiber Concrete (TCRSFC) has increased by 5.18% with respect to Normal Concrete (NC). This increment consistent with increment of natural frequency from free vibration test.

(b) Based on free vibration analysis, damping ratio and natural frequency of Treated Crumb Rubber Steel Fiber Concrete(TCRSFC) column is 9.6% and 11.14Hz while Normal Concrete (NC) column is 4.6%and 10.04 Hz. Inclusion of treated crumb rubber and steel fiber has improve 109% of damping ratio and 10.96% natural frequency.

(c) The peak response acceleration of Treated Crumb Rubber Steel Fiber Concrete(TCRSFC) column (1.21g) is reduce by 37% which is less than Normal Concrete (NC) column (1.91g). This is showing that the presence of treated crumb rubber and steel fiber in concrete mixture helps in reducing seismic force due to an increment in damping ratio.

6. Reference

[1] Xue J and Shinozuka M 2013 Rubberized concrete: A green structural material with enhanced energy-dissipation capability,*Constr. Build. Mater.* **42** 196–204.

[2] Youssf O, EI Gawady M A, Mills J E and Ma X 2014 An experimental investigation of crumb rubber concrete confined by fibre reinforced polymer tubes,*Constr. Build. Mater.***53** 522 -

532.

[3] Naji Hilal N 2017 Hardened properties of self-compacting concrete with different crumb rubber size and content,*Int. J. Sustain. Built Environt.* **6** 191–206.

[4] Khatib Z K andBayomy F M 1999 Rubberized portland cement concrete, *J. Mater.Civil Eng.***11** 206–213.

[5] Noaman T A, Abu Bakar B H and Md Akil H 2015The effect of combination between crumb rubber and steel fiber on impact energy of concrete beams *Procedia Engineering* vol 125(United Kingdom: Elsevier) pp 825–831.

[6] Alawode O and Idowu O 2011 Effects of water-cement ratios on the compressive strength and workability of concrete and lateritic concrete mixes, *Pac. j. sci. technol.* **12**99–105.

[7] Zivica V 2009 Effects of the very low water/cement infrastructures in developing countries,*Constr. Build. Mater.* **23** 3579–3582.

[8] Rahmani K, Shamsai A, Saghafian B and Peroti S 2012 Effect of water and cement ratio on compressive strength and abrasion of microsilica concrete, *Middle-East J. Sci. Res*. **12** 1056–1061.

[9] Atiş C D and Karahan O 2009 Properties of steel fiber reinforced fly ash concrete, *Constr. Build. Mater*. **23**392–399.

[10] Eldin N andSenouci A 1993 Rubber-Tire particles as concrete aggregates,*J. Mater. Civil Eng*. **5** 0899–1561.

[11] Zheng L. Sharon Huo X and Yuan Y 2008 Strength, modulus of elasticity, and brittleness index of rubberized concrete,*J. Mater. Civil Eng.* **20** 692–699.

[12] Waris M B, Ali N N and Al-Jabri K S 2016 Use of recycled tire in concrete for partial aggregate replacement, *Int. J. Struct. Civ. Eng. Res.* **5** 273 - 276.

[13] Herman K and Bisesi M S 2002 *Handbook of Environmental Health, Forth edition, Volume II: Pollutant Interactions in Air, Water and Soil*(United States: CRC press LLC) pp1-83.

[14] Issa C A andSalem G 2013 Utilization of recycled crumb rubber as fine aggregates in concrete mix design,*Constr. Build. Mater.* **42** 48–52.

[15] Moustafa A and Elgawady M A 2015 Mechanical properties of high strength concrete with scrap tire rubber,*Constr.Build. Mater.* **93** 249–256.

[16] Teychenné D C, Nicholls J C, Franklin R E and Hobbs D W 1988*Design of Normal Concrete Mixes, second edition*(London: CRC Ltd - Building Research Establishment) 9–25.

[17] BS EN 1992-1-1 Eurocode 22004 *Design of concrete structures -Part 1-1: General Rules and Rules of Buildings* (London: British Standard) 153–155.

[18] BS 1881-121 1983 *Testing Concrete - Part 121: Method for Determination of Static Modulus of Elasticity in Compression*(London: British Standard) 3–5.

[19] MS 1064-10 2009 *Guide to Modular Coordination in Buildings: Part 10: Coordinating Size and Preferred Size for Reinforced Concrete Component* (Malaysia: Malaysian Standard) 5–8.

[20] Metha P K andMonteiroar P J M 2006 *Concrete Microstructure, Properties, and Materials*, *3rd edition* (United States: McGraw-Hill) pp 89–90.

[21] Inman D J 1994 *Engineering Vibration* (United States: Prentice-Hall) pp 390–463.

[22] Minnetyan L and Batson G B 1984 *Steel Fibrous Concrete under Seismic Loading* Technical Report AD-P003 691 (United States: Department of Civil and Environmental Engineering Clarkson College of Technology) pp 589–597.

Acknowledgement

This work was supported by Ministry of Education Malaysia and Universiti Teknologi Malaysia (UTM) for providing the financial support under FRGS grant Q.J130000.2522.12H44 and partially financed by Smart IBS Sdn. Bhd.