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CONSEQUENCE OF CRACK DEVELOPMENT FOR DYNAMIC BEHAVIOUR OF COIR FIBRE REINFORCED CONCRETE STRUCTURES

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ABSTRACT

The investigations on earthquake resistant structures made of natural fibre reinforced concrete have been initiated. The aim is to make earthquake resistant housing affordable. Natural fibres have the potential to be used in concrete, and coir fibre is the most ductile fibre amongst all natural fibres. As part of this task, coir fibres reinforced concrete (CFRC) beams as structural members have been investigated recently for their static and dynamic properties. The influence of damage on the load transmitting behaviour of CFRC beams along with the alterations in their dynamic properties is addressed in this work. The expansion of damage is simulated by increasing the static load incrementally up to certain deflection prior to each dynamic test. The forces at beam supports are normalized by the dynamic load. It is observed that with increasing damage, the transmitted force is amplified.

Introduction

The awareness of earthquake resistant housing has been increased among common people in many parts of the world. The reason for this awareness is the frequent occurrence of earthquakes, resulting in loses of life and property. Earthquake resistant housing demands overall ductile behaviour of structure without producing large damages, which require sufficient and balance amount of steel in concrete. However, steel reinforcement in many countries is still expensive for many people. Most of them live in low rise buildings, one storey or two storey houses. They cannot afford expensive earthquake resistant houses. An alternate approach for such housing is therefore required, especially in developing countries. This is possible if steel can be replaced by some cheap and durable material like natural fibres. Natural fibres as reinforcement in concrete have been studied by many researchers, but only for non-structural members. Their potential as earthquake resistant structural members needs to be considered. Investigations of low-rise frame building structure made of coir fibre reinforced concrete are intended within this research program in the near future.

Baruah and Talukdar (2007) investigated the compressive strength, splitting tensile strength, modulus of rupture and shear strength of plain concrete and coir fibre reinforced concrete (CFRC) with different fibre volume fractions ranging from 0.5% to 2%. CFRC with 2% fibres showed better results amongst all volume fractions. It was also found that an

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increase in all strengths was observed with an increase in fibres volume fraction. They concluded that tested natural fibres might be good alternatives to relatively more expensive metallic, polyester or glass fibres.

Ghavami (1995) tested bamboo reinforced light-weight concrete beam (120mm width, 300mm depth and 3400mm long) with four point loading up to collapse. The bamboo with section of 30mm x 10mm was used as reinforcement. He concluded that the ultimate applied load was increased up to 400% for the tested beam as compared with the one without bamboo reinforcement. The author also recommended 3% bamboo in relation to the concrete section for the bamboo reinforced concrete beams.

Sivaraja and Kandasamy (2008) determined the ductility and energy absorption for concrete composites reinforced with local materials (coir, rice husk and sugarcane). It was found that no crushing and spilling of concrete occurred during the failure.

Zheng et al. (2008) and Yan et al. (2000) determined the dynamic properties of concrete composites having scrap tires and polyolefin fibres, respectively. Zheng et al. found that damping ratios of grinded and crushed rubberized concrete (45% by volume of aggregate replaced with rubber) could reach as high as 75% and 144%, respectively, as compared to plain concrete. Yan et al. found that an increase in damping was always accompanied by a decrease in response frequencies of the considered fibre reinforced concrete composites.

Experimental Procedure

This is a continuation of previous works, Ali and Chouw 2009a and 2009b, taken as cases I and II, respectively, on coir fibre reinforced concrete (CFRC). In those works, static and dynamic properties of CFRC were determined. Details about casting and testing procedures were given. The difference between two cases is as follows:

Case I	Case II
CFRC was made with natural and treated coir fibres.	CFRC beams were casted without and with coir rope. Only natural coir fibres were used.
10cm long fibres with a fibre content of 1.16% by mass of cement were used.	7.5cm long fibres with a fibre content of 3% by cement mass were used. The diameter and tensile strength of coir rope was 1 cm and 7.8 MPa, respectively.
For plain concrete, mix design ratio for cement, sand and aggregates was 1, 1.5 and 3, respectively, with a water cement ratio of 0.60. This is designated as PC1. Mix design for CFRC was same as that of plain concrete except that the proportion of aggregates was reduced according to added proportion of fibres. This is designated as $CFRC1_N$ and $CFRC1_T$ for CFRC casted with natural and treated coir fibres, respectively.	For plain concrete, mix design ratio for cement, sand and aggregates was 1, 2 and 2, respectively, with a water cement ratio of 0.48. This is designated as PC2. The CFRC was prepared similar to that of case I, and is designated as CFRC2. The water cement ratio used for CFRC2 was 0.56 to make it workable.
The aggregates were of three different sizes; 0 to 6 mm, 12 mm and 20 mm maximum.	The maximum size of aggregates was 12 mm (passing through sieve 12 mm and retained at sieve 10 mm).

The static properties, compressive strength σ, corresponding strain ε, modulus of elasticity (MOE), splitting tensile strength (STS), modulus of rupture (MOR), corresponding deflection Δ and cracking load P_{Crack} are summarised in Table 1. Cracking load is the load taken by fibres after the first visible crack is produced. All values are average of three readings. All the static properties remained, more or less, same. However, CFRC beams did not break into two pieces as did beams of plain concrete beams, ensuring the advantage of fibres.

Table 1: Static properties of plain and coir fibre reinforced concrete for cases I and II

Case	Sample	Cylinder testing				Small beam testing			Density (kg/m^3)
		σ (MPa)	ε (%)	MOE (GPa)	STS (MPa)	MOR (MPa)	Δ (mm)	P_{Crack} (kN)	
I	PC1	40.3	0.23	29.3	*	4.86	*	-	2372
	$CFRC1_N$	43.4	0.27	28.0	*	4.23	*	1.20	2359
	$CFRC1_T$	40.9	0.24	28.5	*	4.17	*	0.97	2353
II	PC2	35.5	0.18	23.2	3.8	4.71	0.64	-	2277
	CFRC2	32.6	0.22	21.1	4.2	5.01	0.69	1.08	2257

* *Not measured*

In this paper, load transmission behaviour at different stages of damage is discussed along with alteration in dynamic properties.

Testing and analysis

Long beam tests

Long beams of 100 mm wide, 100 mm deep and 915 mm long were tested for dynamic properties and load transmission behaviour. An impact load P_i is applied three times within 20 seconds at midspan of the beam with the help of a calibrated hammer. The response is recorded by load cells which represent readings of left and right support reactions, R_{Li} and R_{Ri}, respectively. The impact load is applied three times to take the average of resulting three values of reactions. The same beam is then put under a static load (P_s) of 1kN in the universal testing machine (Fig. 1). Deflection Δ_s and both reactions are recorded using a LVDT (linear variable differential transformer) and load cells, respectively.

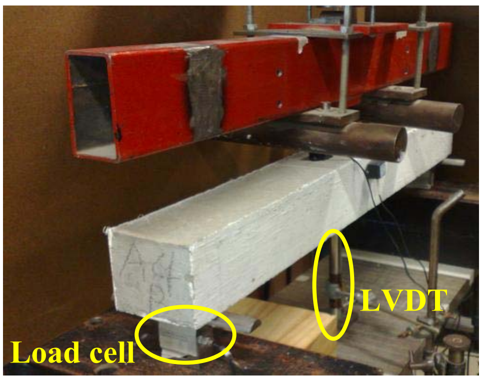


Figure 1: Experimental set up

Again, an impact load is applied three times and the response is recorded. The magnitude of the impact load is kept low so that no additional damage is produced since the goal is to identify the load transmission behaviour and dynamic properties at the static load induced damage stage.

This procedure, static loading and subsequent impact loading, is repeated until failure of the beam. The load before producing the first crack is taken as the reference for the just before crack stage. The response is investigated for four stages; (i) uncracked beam [S1], (ii) just before cracking [S2], (iii) cracked beam [S3] and (iv) after cracks occurred following two cycles [S4a and S4b]. Each cycle consists of applying a static load on the cracked beam up to a certain deflection and then releasing the load for measuring its dynamic load transmission behaviour. Fourth stage is investigated for case II only because of presence of high content of fibres.

Dynamic properties were also investigated from recorded acceleration time histories at considered stages.

Figs. 2 and 3 show typical force displacement curves and the crack development, respectively, for CFRC beam without rope at different stages. Cracked cross-sections and crack profiles of the CFRC long beams without and with rope are shown in Figs. 3 and 4, respectively.

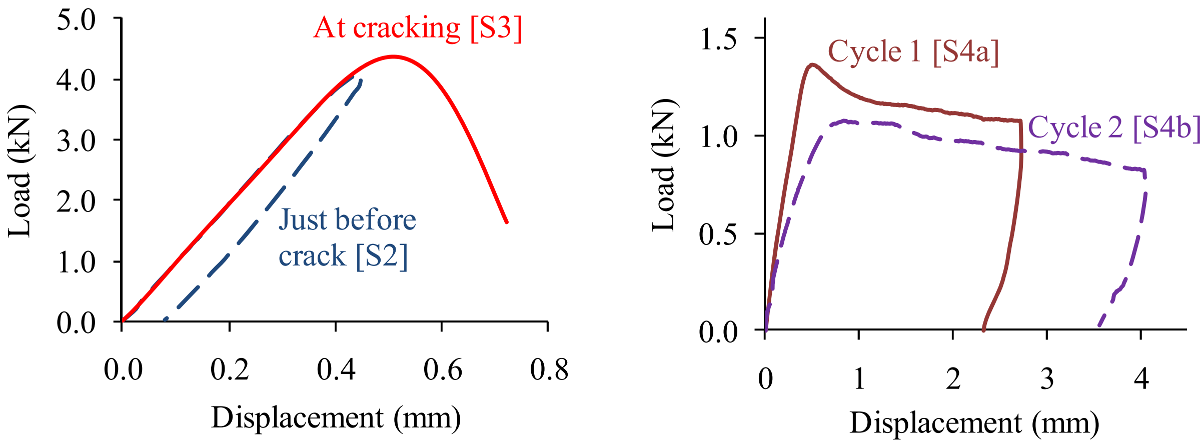
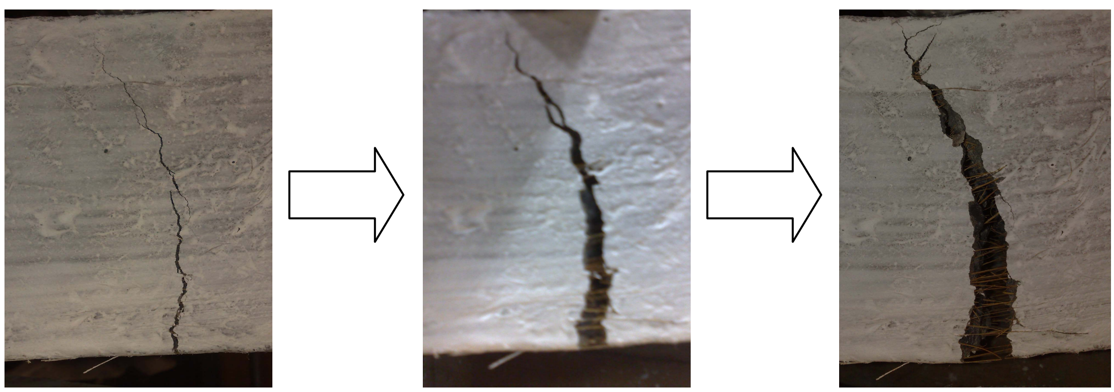
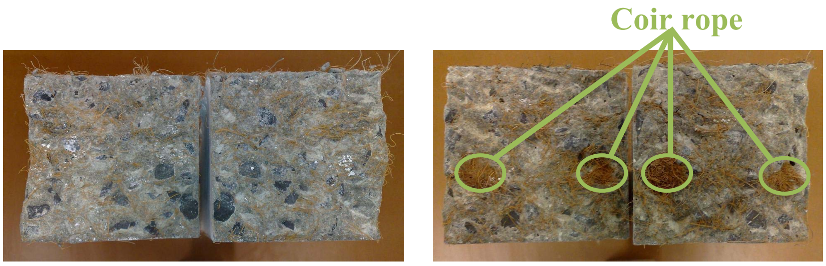


Figure 2: Typical load displacement curves for CFRC beam without rope (Case II)



At cracking [S3] After crack - cycle 1 [S4a] After crack - cycle 2 [S4b]

Figure 3: Crack development (Case II)



(a) Without rope

(b) With rope

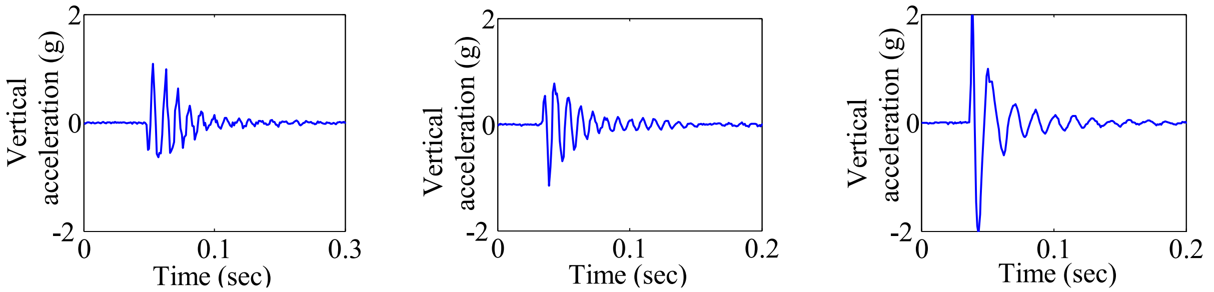
Figure 4: Cross-sections of CFRC long beams (Case II)

Figure 5: Crack profiles (Case II)

Dynamic properties of long beams

The logarithmic decrement was used for calculating the damping ratio ξ from the recorded acceleration time histories. Natural frequency f was calculated from the period of the recorded acceleration, and it can be used to define the actual beam Young's modulus at considered damage stages.

The acceleration time histories of the CFRC beam without rope are shown in Fig. 6. The alteration of dynamic properties of CFRC beams for both cases are shown in Figs. 7 and 8, respectively. It can be clearly seen that the damping of cracked CFRC beams increases, while the natural frequency decreases.

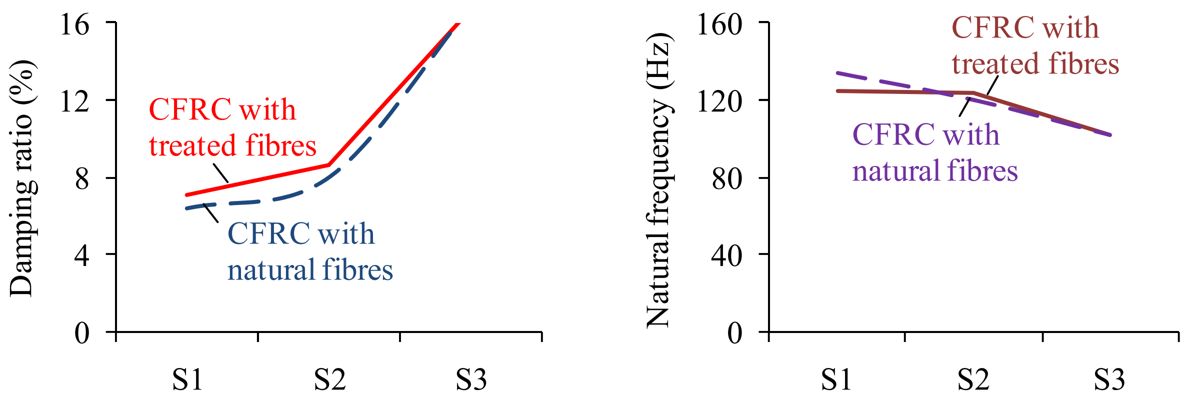


(a) Uncracked beam [S1]

(b) Cracked beam [S3]

(c) After crack - cycle 2 [S4b]

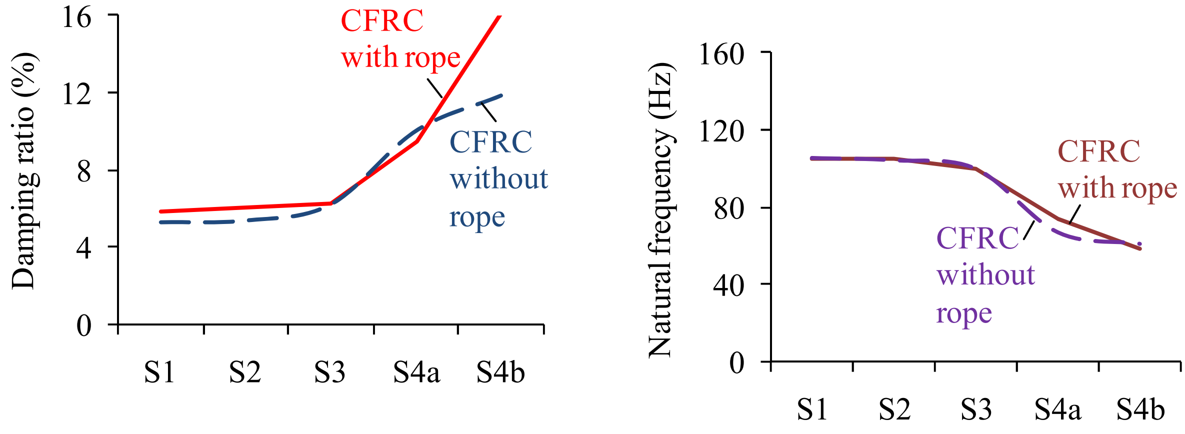
Figure 6: Recorded acceleration time histories of CFRC beam without rope (Case II)



(a) Damping ratio

(b) Natural frequency

Figure 7: Alteration of dynamic properties of CFRC beams with increasing damage (Case I)



(a) Damping ratio (b) Natural frequency

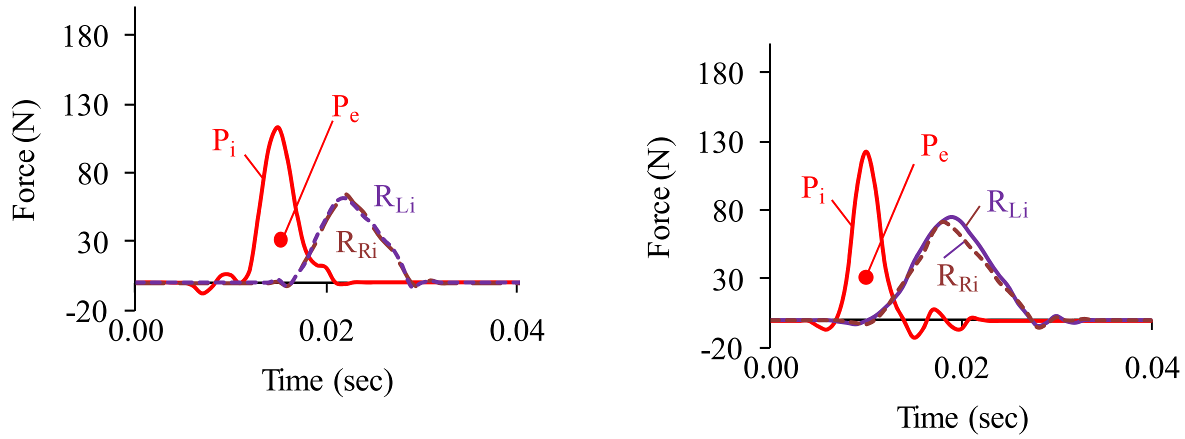
Figure 8: Alteration of dynamic properties of CFRC beams with increasing damage (Case II)

Load transmission behaviour

Fig. 9 shows the recorded applied impact load P_i, reaction forces at the left and right support R_{Li} and R_{Ri}, respectively, for a CFRC beam without rope at stage 1 and 4a (case II). Their maximum values are highlighted in Table 2.

The area under the curve of P_i is taken as P_e and is used for normalization of reaction forces at the supports. Normalization of transmitted forces for considered stages are presented in Table 2. Fig. 10 compares the normalized reactions at stages 1 and 4a for both supports (CFRC beam without rope, case II).

It is observed that the maximum transmitted load is amplified as the summation of maximum reactions at both supports is more than the applied impact load. The distribution of impact load towards both supports is not equal for each considered stage.



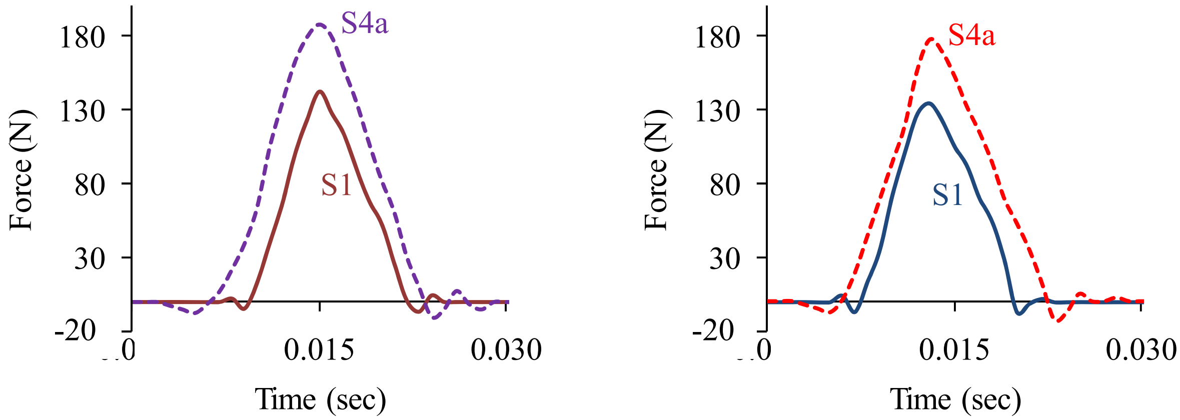
(a) Uncracked beam [S1] (b) After crack - cycle 1 [S4a]

Figure 9: Recorded applied impact load, reactions and normalized reactions of CFRC beam casted without rope at stage 1 and 4a (case II)

Table 2: Experimental results

Case	Specimen	Considered Stages	Static load						Impact load					
			Recorded data				Normalized reactions		Recorded data			Area under curve	Normalized Reactions	
			P_s (kN)	Δ_s (mm)	R_{Ls} (kN)	R_{Rs} (kN)	R_{Ls}/P_s	R_{Rs}/P_s	P_i (N)	R_{Li} (N)	R_{Ri} (N)	P_e (Ns)	R_{Li}/P_e	R_{Ri}/P_e
I	CFRC (with natural fibres)	S1	-	-	-	-	-	-	231	128	127	0.623	205	204
		S2	4.05	0.45	2.02	2.02	0.499	0.499	127	74	75	0.350	211	214
		S3	4.58	0.56	2.28	2.30	0.498	0.502	249	139	144	0.569	244	253
	CFRC (with treated fibres)	S1	-	-	-	-	-	-	218	119	121	0.537	222	225
		S2	5.19	0.52	2.59	2.59	0.499	0.499	190	125	118	0.512	244	230
		S3	5.55	0.58	2.76	2.79	0.497	0.503	227	144	133	0.562	256	237
II	CFRC without rope	S1	-	-	-	-	-	-	113	64	61	0.455	142	135
		S2	4.08	0.44	2.04	2.04	0.500	0.500	138	81	72	0.442	183	163
		S3	4.21	0.46	2.12	2.09	0.504	0.496	152	82	73	0.445	184	164
		S4a	1.36	0.50	0.69	0.67	0.507	0.493	121	75	71	0.401	187	177
		S4b	1.06	0.83	0.535	0.525	0.505	0.495	169	96	90	0.499	192	180
	CFRC with rope	S1	-	-	-	-	-	-	118	66	65	0.387	171	168
		S2	5.00	0.54	2.50	2.50	0.500	0.500	73	44	46	0.239	184	192
		S3	5.25	0.56	2.63	2.62	0.501	0.499	166	90	92	0.391	230	235
		S4a	1.56	0.75	0.79	0.77	0.506	0.494	157	83	85	0.346	240	246
		S4b	0.99	2.37	0.46	0.45	0.505	0.495	218	124	130	0.475	261	274

Note: (1) P_s, Δ_s, R_{Ls}, R_{Rs}. P_i, R_L and R_{Ri} are defined under section "Long beam tests".
(2) The highlighted values are obtained from Figs. 2, 9 and 10 for respective tested stages.



(a) Normalized left support Reaction force (R_{Li} / P_e)

(b) Normalized right support Reaction force (R_{Ri} / P_e)

Figure 10: Normalized reaction forces for CFRC beam without rope at stage 1 and 4a (case II)

To understand the experimental results, calculations are performed using the response spectrum of half sine impact load (Fig. 11). For simplicity, the following assumptions are made: (i) the beam is modeled as a single-degree-of-freedom (SDOF) system, (ii) the damping is neglected, (iii) the mass of the beam does not change due to damage and (iv) the load is approximated as a half sine impact with the maximum value of P_i. Since the applied impact should not cause additional damage, the system at a particular damage stage responds to the load linearly. The damage at different stages due to static load is reflected in different stiffness of the system. The ratios of duration t_d of the impact load to the natural period T_n of the CFRC beam for different damage stages are calculated, and the respective responses u_o are obtained from Fig. 11. The stiffness of the beam at considered stages is calculated from the recorded natural period and the mass. The response u_o is proportional to the total reaction force. The total reaction force is, however, also the product of the actual stiffness and the response u_o at considered damage stage.

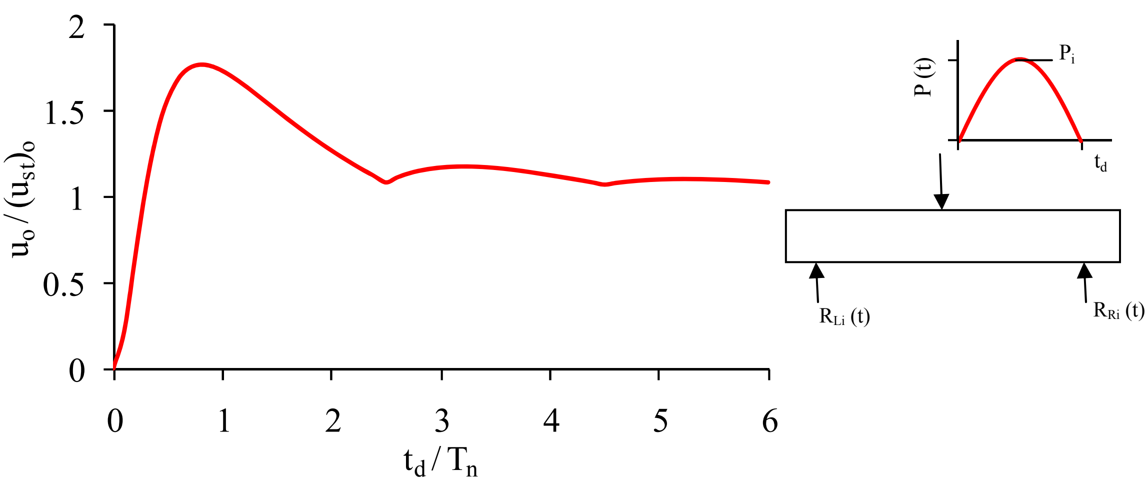


Figure 11: Maximum response to half cycle impact load

Fig. 12 shows the comparison of the calculated and experimental total reaction force for considered damage stages. Both values have the same tendency. The difference is caused by the simplified assumptions of the SDOF system.

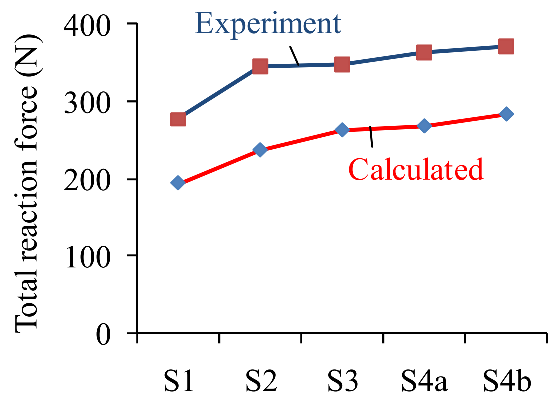


Figure 12: Comparison of calculated and experimental reaction summation for CFRC beam without rope (case II)

On the other hand, static load is transmitted approximately equally towards both supports up to linear stage as shown in Table 2. However, when cracks occur close to one support, more load is transmitted to the other support.

Concluding Remarks

Coir fibre reinforced concrete beams were tested for their load transmission behaviour and dynamic properties at different stages of damage. The experimental result reveals the following information:

- In the considered cases, the transmitted dynamic load is amplified with increasing damage. This finding coincides with the calculated results.
- Damping of cracked CFRC beams increases, while the natural frequency decreases.
- Static load is transmitted approximately equal up to linear stage, and then transmitted forces vary between the two supports depending upon crack location.

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References

Ali, Majid and Chouw, Nawawi (2009a). "Dynamic testing of coir fibre reinforced concrete beam." *8th international conference on "Shock and Impact Load on Structures"*, In printing.

Ali, Majid and Chouw, Nawawi (2009b). "Coir fibre and rope reinforced concrete beams under dynamic loading." *Annual Australian Earthquake Engineering Conference - 2009 "Newcastle Earthquake – 20 years on"*, In printing.

Baruah, P., and Talukdar, S. (2007). "A comparative study of compressive, flexural, tensile and shear strength of concrete with fibres of different origins." *Indian Concrete Journal*, 81(7), 17-24.

Chopra, Anil K. (2007), "Dynamics of structures, Theory and applications to earthquake engineering – Third edition." Article 4.8, 143-148.

Ghavami, K. (1995). "Ultimate load behaviour of bamboo reinforced light-weight concrete beams." *Cement and concrete composites*, 17(4), 281-288.

Sivaraja, M., and Kandasamy, S. (2008). "Characterization of concrete composites for energy absorption." *Journal of Reinforced Plastics and Composites*, 27(2), 135-144.

Yan, L., Jenkins, C. H., and Pendleton, R. L. (2000). "Polyolefin fiber-reinforced concrete composites. Part I. Damping and frequency characteristics." *Cement and Concrete Research*, 30(3), 391-401.

Zheng, L., Sharon Huo, X., and Yuan, Y. (2008). "Experimental investigation on dynamic properties of rubberized concrete." *Construction and Building Materials*, 22(5), 939-947.