A study of the dynamic mechanical properties of CRTS I type CA mortar

X. H. Zeng ^{a, b, c}, Y. J. Xie ^{c, *}, D. H. Deng ^c, P. Wang ^{a, b}, F. L. Qu ^a

^a School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, P R China

^b Key Laboratory of High-speed Railway Engineering of the Ministry of Education, Chengdu
610031, P R China

^c School of Civil Engineering, Central South University, Changsha 410075, P R China

Abstract: Cement and emulsified asphalt mortar (CA mortar) consists of cement, emulsified asphalt, sand, water, and other additives, which can be used as a vibration attenuator and isolation casting layer in modern high-speed railway. However, the dynamic mechanical properties of CA mortar have not been well documented until now. In this paper, a series of experiments were carried out to characterize the dynamic properties of CA mortar. It can be found from the test results that the compressive strength, the compressive strain, and the elastic modulus are much more sensitive than traditional Portland cement mortar and concrete in a specified range of strain rate. Meanwhile, experimental results from an impacting acceleration test presents that CA mortar had excellent vibration attenuation and isolation functions.

Key words: CA mortar; dynamic mechanics; vibration; strain rate

1. Introduction

* Corresponding author. School of Civil Engineering, Central South University, 410075 Chshangsha, P R China. Tel./Fax: +86 731 26568568

E-mail address: yjxie2007@163.com (Y. J. Xie)

Cement and emulsified asphalt mortar (CA mortar) is a composite material consisting of cement, emulsified asphalt, sand, and admixtures, and is widely used in high-speed railway in China, Japan and Germany [1-6]. In CRTS (China Railway Track System) I-type track systems, CA mortar is cast between the concrete bed plate and the track slab to providing leveling, support as well as vibration absorption and segregation (Fig. 1).

Fig .1 Structure of CRTS I track system

In the CRTS I-type track system, the loadings on the CA mortar can be distinguished as static and dynamic. The static load mainly is composed of the gravity of the track slab and the steel track while the dynamic load is complex and related to the vehicle-track interaction. In ideal condition, the dynamic load can be taken as simulated by using cosine rule. However, the dynamic load will be irregular and abrupt when the vehicle-track system is out of order, especially when the speed of the train is high which will lead to high-speed loading. In literatures [7-9], impact vibrations affecting high-speed railway are mainly caused by welded rail joints, corrugated rails, flat wheels, eccentric wheels, and non-circular wheels. In such a complex dynamic system, It is quite difficult to guarantee the safety of the train.

Therefore, the exploration of mechanisms vibration absorption and segregation of

CA mortar is very important to improve the performance of CA mortar and the design of dynamic railway track systems. The vibration acceleration method is widely used to characterize the vibration of structure. Wang et al ^[10] used the vibration acceleration method to investigate the vibration segregation of floating slab track and ballast bed track. Lian et al ^[11] used this method to evaluate the stability of different track systems. Tao ^[12] used it to analyze the attenuation mechanism of vibrations induced by a train and optimize the design vibration prevention and segregation methods for buildings.

Compared with Portland cement mortar, the mechanical properties of CA mortar at different loading rates were studied in this paper. The relationship between compressive strength, compressive strain, elastic modulus, and strain rate were established. The vibration accelerations of CA mortar and concrete were tested by acceleration meters by using a dropped hammer. The impact resistance of CA mortar was also studied using the modified drop-weight test as described in ACI 544-2R-89.

2. Experimental details

2.1 Materials

Normally, the dry mixed mortar components including cement, sand, aluminum powder, and other admixtures are premixed, and then mixed with emulsified asphalt in the field for quality control and time saving.

In the study, the premixed mortar was used according to the standard of DSTMR C 74-2008 ^[13]. Sand with a fineness modulus of 1.7 was used. 65% of the premixed mortar remained in the 0.075 mm sieve. Its one-day linear expansion rate was 1.8%. Emulsified asphalt with a solid content (residue content) of 60.5% was used. The

Engle viscosity of the emulsified asphalt was 6.0. The penetration degree of the residue was 68 (0.1 mm), and its ductility at 5°C was 215 mm.

The A/M (emulsified asphalt to dry mixed mortar) ratio of the CA mortar was 0.45 and additional water was added to adjust the fluidity. The “J” type funnel flowing time of the fresh CA mortar was 24 s, and its segregation degree was 0.2%. The testing methods of flowing time and segregation degree can be seen in literature [5]. The compressive strengths of the CA mortar were 0.5 MPa and 2.0 MPa at ages of 1 day and 28 days, respectively. All of these parameters fulfill the standard of DSTMR C 74-2008 [13].

2.2 Experiments

(1) Compressive experiments under different strain rates

For the CA mortar with the thickness of 50 mm and elastic modulus of 200 MPa, the velocity of the dropping platform were set to 0.01, 0.05, 0.10, 0.20, 0.50, 1.00, 2.00, 5.00, 10.00, 15.00, 20.00, 50.00, 100.00, and 200.00 mm/min in these experiments since the dynamic stress of a normal high-speed train is 0.02–0.2 MPa with a frequency of 1-5 Hz [14-15]. The samples have been pre-pressed for three times under one-third of their compressive strengths before the experiments. The compressive strength on the stress-strain curve was the compressive strength (f_d) and its corresponding strain was the compressive strain (ε_d). The elastic modulus (E_d) was calculated by the secant modulus of 0–1/3 compressive strength. The data of asphalt binder and asphalt concrete were distilled from the picture of literature [16] using the software of GetData Graph Digitizer v2.25.

(2) Impact acceleration experiment

The impact acceleration experiment was carried out as shown in Fig. 2. The acceleration meter used was produced by Integrated Measurement & Control (IMC). Two acceleration sensors were adhered on the surface of the steel board and the specimen by using epoxy resin. Channels one and four of the IMC were connected to the sensor adhered on the specimen and the sensor adhered on the steel board at the bottom. A steel hammer dropped freely due to the force of gravity, shocking on the steel ball above the specimen. The vibration acceleration of the specimen and steel board were recorded by the acceleration sensors as described before. The data were recorded by a computer. The experiments were conducted on concrete and CA mortar specimens.

Fig. 2 Setup of the vibration acceleration test

(3) Impact resistance experiment

According to the ACI 544-2R-89 (1999) drop-weight test (Measurement of Properties of FRC), A $\Phi 100 \times 50$ mm specimen was adopted to replace a $\Phi 150 \times 64$ mm specimen used in ACI 544-2R-89, because large specimens were difficult to crack (needing nearly 1000 impact repetitions), and it is quite difficult to distinguish the first crack in such a large specimen. In contrast, a $\Phi 100 \times 50$ mm specimen broke into

two parts immediately. The other conditions were the same as those specified in ACI 544-2R-89. The impact energy is calculated by

$$W = N mgh \quad (1)$$

Where W is the impact energy; N is the number of impaction cycles; m is the weight of the hammer, 4.54 kg; g is the acceleration of gravity, $9.81 \text{ m}\cdot\text{s}^{-2}$; h is the initial height of the hammer, 457 mm.

3. Results and discussion

3.1 Stress-strain curve of CA mortar and Portland cement mortar

As shown in Fig. 3, the stress of CA mortar showed no marked decrease after the peak stress, in contrast to Portland cement mortar. The CA mortar seemed to have good toughness and ductility, and could endure large deformation. The asphalt notably altered the brittleness of cement.

Fig. 3 Stress-strain curves of CA mortar and Portland cement mortar at different strain rates

The compressive strength (f_d) of CA mortar increased with the strain rate. As the strain rate increased from $3.3 \times 10^{-6} \text{ s}^{-1}$ to $1.7 \times 10^{-2} \text{ s}^{-1}$, its compressive strength

increased from 1.3 MPa to 5.0 MPa. Both mortars were “impact toughness” for the compressive strength strain (ε_d) of those increased with the strain rate [17]. The stress-strain relationship of CA mortar is nonlinear at low stress levels while the stress-strain relationship of Portland cement mortar is linear before damage expect for nonlinear deformation in the initial phase caused by the non-smooth surface of the cement mortar specimen. There is no big difference between the stress-strain curves for Portland cement mortar at different strain rates.

3.2 Mechanical properties of CA mortar at different strain rates

(1) The compressive stress as a function of strain rate

As shown in Fig. 4, numerous literatures can be found about the strain rate effects on the dynamic strength of concrete [18-35]. But a little literature can be found about asphalt materials [16]. These literatures had proved that the dynamic increase factor (DIF) of concrete strength as a function of strain rate could be divided into two region. In the low strain rate region, the DIF increased slightly with the increasing strain rate, and in the high strain rate region, the DIF increased very fast. For concrete-type materials (concrete or mortar with little to no organic material content), the Comité Euro-International du Béton (CEB) [36] proposed a formula of dynamic compressive strength (f_d) and strain rate ($\dot{\varepsilon}_d$) referring to a quasi-static condition when the strain rate are lower than 30 s^{-1} or higher than 30 s^{-1} , shown in the following equations:

$$f_d = f_q (\dot{\varepsilon}_d / \dot{\varepsilon}_q)^{1.026/(5+0.9f_q)} \quad \dot{\varepsilon}_d \leq 30 \text{ s}^{-1} \quad (2)$$

$$f_d = \gamma (\dot{\varepsilon}_d)^{1/3} \quad \dot{\varepsilon}_d > 30 \text{ s}^{-1} \quad (3)$$

Where f_q is the compressive strength in a quasi-static condition; $\dot{\varepsilon}_q$ is the strain rate

in a quasi-static condition. Usually, the strain rate in a quasi-static condition was about $3.0 \times 10^{-5} \text{ s}^{-1}$. The $\lg \gamma = 6.156 / (5 + 0.9 f_q) - 0.492$.

Fig. 4 DIF of compressive strength versus strain rate

In Fig. 4, it can be found from the experiment results that the change law of DIF of compressive strength of Portland cement mortar keeps in good agreement with those of concrete in literature, where the DIF of compressive strength increased slightly with the increasing strain rate. However, for the asphalt concrete, the asphalt binder and the CA mortar, the change law is significantly different from those of the concrete. Even in low strain rate, the compressive strengths of the three materials were much more sensitive to the strain rate than that of the concrete. Furthermore, the asphalt concrete and asphalt binder were more sensitive to strain rate than CA mortar.

As shown in Fig. 5, for the hydration of cement, the binder of CA mortar content includes cement gel and asphalt. The rigid cement gel would reduce the sensitivity to strain rate of compressive strength. The binder of asphalt binder and asphalt concrete is asphalt gel comprising of limestone powder. Compared to cement, the limestone

powder is inert, and only asphalt gel can contribute to the binding. As a result, the compressive strength of asphalt concrete and asphalt binder were more sensitive to strain rate than that of CA mortar. For interface between asphalt binder and aggregate in the asphalt concrete, the thickness of the asphalt binder is thin which can induce ultimate condition easily. The relaxation and the creep of asphalt concrete are very high. Therefore, the compressive strength of asphalt concrete is most sensitive to strain rate.

Fig. 5 SEM analysis of CA mortar

(2) The compressive strain as a function of strain rate

As shown in Fig. 6, in literature, for concrete, the change law of compressive strain with strain rate is contradictable. Many literatures showed that the DIF of compressive strain decrease with the increasing strain rate [20, 24, 26, 28, 37-40]. But also many literatures showed that it do not decrease with the increasing strain rate [21-23, 41-45]. Bischoff and Perry [34] presents that the compressive strain should increase with the increasing strain rate. The discrepancy may come from several factors such as quasi-static compressive strength, aggregate type, curing and testing

condition, especially the failure form. The integrity of stress-strain curve and the loading system will deeply influence the testing results. In literature [38], the author presents that the creep plays an important role in the compressive strain which leads to the increasing of compressive strain and decreasing of limit stress under low strain rate.

Fig. 6 DIF of compressive strain versus strain rate

As shown in Fig. 6, similar to concrete, the compressive strain of Portland cement mortar increase slightly with the increasing strain rate. But for asphalt binder and CA mortar, the compressive strain increases rapidly with the increasing strain rate. This phenomenon is attributed to the impacting strain hardening material. However, for the asphalt concrete, the rule is different from that of asphalt binder and CA mortar. Similarly, because asphalt concrete has more interfaces of asphalt binder and aggregate. The asphalt binder thickness is thin and easily to be under ultimate condition. As a result, the creep is remarkable in low strain rate, and the compressive strain of the asphalt concrete is un-sensitive to strain rate. For CA mortar, because the matrix comprises of rigid cement gel and asphalt, the creep of it is relatively small.

(3) The elastic module as a function of strain rate

As shown in Fig. 7, the change law of elastic module of Portland cement mortar is same to that of concrete which increase slowly with the increasing strain rate [46-48]. The elastic modules of asphalt concrete increased much more rapidly than those of other materials. Due to the interface of asphalt binder and aggregate, the elastic module of asphalt concrete is most sensitive to strain rate. Owing to the asphalt, elastic module of asphalt binder and CA mortar were more sensitive to strain rate than concrete.

Fig. 7 DIF of elastic modulus versus strain rate

As CA mortar designed as a material with vibration absorption and vibration isolation properties, strain rate sensitivity of the elastic modulus is a key parameter for CA mortar. High loading rate were used to investigate the influence of high speed train. For example, when the dynamic load of the train is 0.05 MPa at normal conditions, and the quasi-static elastic modulus of CA mortar is 200 MPa, the deformation of the layer is 0.0125 mm when the thickness of the CA mortar is 50 mm. When the dynamic load increases to 0.3 MPa due to the vibration of the train-track

system, the deformation will be 0.075 mm if the strain rate sensitivity index of elastic modulus is 0. However, if the CA mortar is sensitive to the strain rate and its elastic modulus increased to 1000 MPa, the deformation will be 0.015 mm. The vibration amplitude will be decreased by 80% by using the sensitive CA mortar.

3.3 Vibration acceleration of CA mortar during impact

Changes in the vibration acceleration of the specimens and steel board over time, CA mortar subjected to the impact of a dropped hammer, are shown in Figs. 8 and 9. The acceleration-time curve of the CA mortar specimen has three attenuation periods which is different with that of a concrete specimen. In the last attenuation period, the vibration acceleration of CA mortar attenuated to zero quickly. Furthermore, the time needed for the vibration acceleration to attenuate to 0.1 g after impact was 0.096 s for concrete and 0.084 s for CA mortar. This result means that CA mortar has better vibration-absorbing properties than concrete.

(a) Concrete specimen

(b) CA mortar specimen

Fig. 8 Vibration acceleration-time curves of the impact specimens

Fig. 9 Vibration acceleration-time curves of the steel board under the impact object

Similarly, the steel board under the CA mortar specimen had three attenuation periods. The time needed for the vibration acceleration of steel board under CA mortar to attenuate to 0.1 g was shorter than when that of steel board under the concrete specimen. The vibration accelerations of both the specimen and the steel board were nearly zero before impact when using CA mortar, but when using concrete the vibration acceleration caused by the surroundings noise was 0.1 g. This result means that CA mortar has good vibration isolation properties, especially when separating small vibrations.

3.4 Impact resistance of CA mortar

In the high-speed railway systems, CA mortar will endure larger impact loading, especially when the rail track is not smooth or the train is out of order. Impact resistance is a key property when CA mortar is used as a packed layer under the track slab, where chemical corrosion and light aging will not happen. As shown in **Table 1**, concrete with a grade of C50 could only endure two impacts, while C30 concrete

could only endure one. However, for CA mortar, although its compressive strength was only about 2.5 MPa (quasi-static condition), it was able to resist five to seven times of impact. The impact energy of CA mortar was much greater than that of the concrete.

Table 1 Impact resistance times of CA mortar and concrete

No.	Sample	Number of impacts	Impact energy (J)
1	Concrete (C50)	2	204.3
2	Concrete (C50)	2	204.3
3	Concrete (C30)	1	102.2
4	CA mortar	5	511.0
5	CA mortar	7	715.3

As shown in **Fig. 10**, impact energy can be absorbed by the deformation of CA mortar, while concrete could not endure large deformation and had no distinct impact traces after the impact. For viscoelastic objects, the mechanical property is a function of strain rate and viscous coefficient. CA mortar will be strengthened in high-speed load (impact).

(a) Concrete specimen

(b) CA mortar specimen

Fig. 10 Specimens after impact test

4. Conclusion

(1) The stress in CA mortar decrease slightly after reaching peak value. It can be found that CA mortar has high impact toughness and ductility, in comparison with traditional concrete and Portland cement mortar.

(2) Compared to concrete and Portland cement mortar, compressive strength value, and elastic modulus is more sensitive to the applied strain rate on CA mortar. The strain rate sensitivity of CA mortar is in good agreement with asphalt concrete and asphalt binder.

(3) It can be found from the impact acceleration experiment that the CA mortar has better vibration attenuation and isolation properties than concrete specimen.

(4) Small strain fluctuations were induced by the strain rate sensitivity of the elastic modulus in CA mortar was subjected to large stress fluctuations. The observed phenomenon can be attributed to the visco-elastic property of CA mortar.

Acknowledgement

This work was financially supported by the National Science Foundations of P R China 51208439, 51078320 and the Fundamental Research Funds for the Central Universities of China 2682015CX085.

Reference

[1] Coenraad E. Recent development in slab track. European Railway Review, 2003; 9(2): 81-85.

[2] Shigeru M, Hideyuki T, Masao U, et al. The mechanism of railway tracks. Japan

277 Railway and Transportation Review, 1998; 15(3): 38-45.

278 [3] Murata O. Overview of recent structure technology R&D at RTRI. Quarterly
279 Report of RITI, 2003; 44(4): 133-135.

280 [4] Katsuoshi A. Development of slab tracks for Hokuriku Shinkansen line. Quarterly
281 Report of RITI, 2001; 42(1): 35-41.

282 [5] Zeng XH, Xie YJ, Deng DH. Conductivity behavior of the fresh CA mortar and its
283 relationship with the fluidity properties. Construction and Building Materials,
284 2012; 36(10): 890–894.

285 [6] Zeng XH. Studies on characteristic of CA mortar and construction quality control
286 of packing layer. P.h.D dissertation. Changsha, China: School of Civil Engineering
287 and Architecture, Central South University, 2010. (In Chinese)

288 [7] Vér IL, Ventres CS, Myles MM. Wheel/rail noise-Part III: Impact noise generation
289 by wheel and rail discontinuities. Journal of Sound and Vibration, 1976; 46(3):
290 395-417.

291 [8] Zhai WM. Characteristics of wheel/rail impact vibrations in high-speed rail way
292 operation and their control principles. Journal of the China Railway Society, 1995;
293 17(3): 28-33. (In Chinese)

294 [9] Wu TX, Thompson DJ. On the impact noise generation due to a wheel passing
295 over rail joints. Journal of Sound and Vibration, 2003; 267(3): 485-496.

296 [10] Wang Lan, Xuan Yan, Wang Jia, et al. The simulation research on the vibration
297 insulation performance of the floating slab track structure. China Railway Science,
298 2005; 26(6): 48-52. (In Chinese)

299 [11]Lian SL, Yang WZ, Liu Y. Test of dynamic behavior of the track structures with
300 different types of sleepers. Journal of the China Railway Society, 2010; 32(2):
301 131-136. (In Chinese)

302 [12]Tao LJ, Li XL, Lu X, et al. Study on attenuation law of ground motion induced by
303 subway shock. World Earthquake Engineering, 2003; 19(1): 83-87. (In Chinese)

304 [13]DSTMR (Department of Science and Technology, the Ministry of Railways of P
305 R China) Code 74-2008. Temporary Technology Criterion for Cement and
306 Emulsified Asphalt Mortar of CRTS I Type Slab Track in a Passenger Dedicated
307 Railway. Beijing: China Railway Press, 2008. (In Chinese)

308 [14]China Academy of Railway Science. General report of Integrated Experimental
309 Section for Ballastless Track of Suining-Chongqing Railway[R]. Beijing, 2007:
310 15-44. (In Chinese)

311 [15]China Academy of Railway Science. General report of Integrated Experimental
312 Section of Wuhan-Guangzhou Railway[R]. Beijing, 2009: 41-65. (In Chinese)

313 [16]Katsuki D, Gutierrez M. Viscoelastic damage model for asphalt concrete. Acta
314 Geotechnica, 2011; 6:231-241.

315 [17]Young J. F., MINDESS S, GRAY R J and BENTUR A. The Science and
316 Technology of Civil Engineering Materials. Beijing: China Architecture &
317 Building Press, 2006: 60-61.

318 [18]Evans RH. Effect of rate of loading on some mechanical properties of concrete, In:
319 Mechanical Properties of Non-Metallic Brittle Materials. Butterworths, London,
320 1958; p. 175-190.

321 [19]Horibe T, Kobayashi R. On mechanical behavior of rock under various
322 loading-rates. J Soc Mater Sci 1965; 14(141): 498–506. (in Japanese)

323 [20]Mahin SA, Bertero VV. Rate of loading effects on uncracked and repaired
324 reinforced concrete members. Report No. UCB/EERC 72-9, Earthquake
325 Engineering Research Center, University of California, Berkeley, 1972.

326 [21]Watstein D. Effect of straining rate on the compressive strength and elastic
327 properties of concrete. ACI J 1953; 49(4): 729–44.

328 [22]Cowell WL. Dynamic properties of plain Portland cement concrete. Technical
329 Report No. 8447, US Naval Civil Engineering Laboratory, Port Hueneme,
330 California, 1966.

331 [23]Atchley BL, Furr HL. Strength and energy absorption capabilities of plain
332 concrete under dynamic and static loadings. ACI J 1967; 64(11): 745–56.

333 [24]Hjorth O. Ein Beitrag zur Frage der Festigkeiten und des Verbundverhaltens von
334 Stahl und Beton bei hohen Beanspruchungsgeschwindigkeiten (dissertation).
335 Braunschweig: Braunschweig Techn Univ, Heft 32,1976.

336 [25]Popp C. Untersuchungen über den Stossverlauf beim Aufprall von
337 Kraftfahrzeugen auf Stützen und Rahmenstiele aus Stahlbeton. Deutscher
338 Ausschuss für Stahlbeton, Heft 281, Berlin, 1977.

339 [26]Hughes BP, Watson AJ. Compressive strength and ultimate strain of concrete
340 under impact loading. Magazine of Concrete Research 1978; 30(105): 189-99.

341 [27]Fagerlund G, Larsson B. Impact strength of concrete. Stockholm: Stockholm
342 Press; 1979.

- [28]Dilger WH, Koch R, Kowalczyk R. Ductility of plain and confined concrete under different strain rates. ACI J 1984; 81(1): 73-81.
- [29]Malvern LE, Jenkins DA, Tang T, Ross CA. Dynamic compressive testing of concrete. In: Proceedings of 2nd Symposium on the Interaction of Non-Nuclear Munitions with Structures; 1985; Florida, US Dept Defense, p. 194-99.
- [30]Suaris W, Shah SP. Inertial effects in the instrumented impact testing of cementitious composites. Cement Concr Aggreg 1981; 3(2): 77-83.
- [31]Ross CA, Thompson EY, Tedesco JW. Split-Hopkinson pressure bar tests on concrete and mortar in tension and compression. ACI Mater J 1989; 86(5): 475-81.
- [32]Ross CA, Joseph W, Tedesco JW, Steven TK. Effects of strain rate on concrete strength. ACI Mater J 1995; 92(1): 37-47.
- [33]Ross CA, Jerome DM, Tedesco JW, et al. Moisture and strain rate effects on concrete strength. ACI Mater J 1996; 93(3):293-300.
- [34]Bischoff PH, Perry SH. Compressive behavior of concrete at high strain rate. Materials and Structures, 1991; 24:425-450.
- [35]Gary G, Baily P. Behavior of quasi-brittle material at high strain rate: experiment and modeling. European Journal of Mechanics 1998; 17(3): 403-420.
- [36]Comite' Euro-International du Be'ton, CEB-FIP Model Code 1990. Redwood Books, Trowbridge, Witshire, UK, 1993.
- [37]Katsuta T. On the elastic and plastic properties of concrete in compression tests with high deformation velocity, Part 1. Trans Inst Jpn Arch 1943; 29: 268-74. (in

365 Japanese)

366 [38]Katsuta T. On the elastic and plastic properties of concrete in compression tests
 367 with high deformation-velocity, Part 2. Trans Inst Jpn Arch 1944; 33: 53-54. (in
 368 Japanese)

369 [39]Ban S, Muguruma H. Behavior of plain concrete under dynamic loading with
 370 straining rate comparable to earthquake loading[A]//2nd World Conference on
 371 Earthquake Engineering[C]. Science Council of Japan, Tokyo, 1960; p.1979–93.

372 [40]Paulmann K, Steinert J. Concrete under very short-term loading. Beton 1982;
 373 32(6): 225-228.

374 [41]Hatano T, Tsutaumi H. Dynamic compressive deformation and failure of concrete
 375 under earthquake load[A]//2nd World Conference on Earthquake Engineering[C].
 376 Science Council of Japan,Tokyo, 1960; p.1963–78.

377 [42]Bresler B, Bertero VV. Influence of high strain rate and cyclic loading of
 378 unconfined and confined concrete in compression. In: Proceedings of 2nd
 379 Canadian Conference On Earthquake Engineering, Hamilton, Ontario, 1975; p.
 380 1-13.

381 [43]Takeda J, Tachikawa H. The mechanical properties of several kinds of concrete at
 382 compressive, tensile, and flexural tests in high rates of loading. Trans Architect
 383 Inst Jpn 1962; 77: 1–6. (in Japanese)

384 [44]Rostasy FS, Hartwich K. Compressive strength and deformation of steel fiber
 385 reinforced concrete under high rate of strain. Int Cem Compos Light Weight
 386 Concr 1985; 7(1): 21–28.

[45]Ahmad SH, Shah SP. Behavior of hoop confined concrete under high strain rates.

ACI J 1985; 82(5): 634-647.

[46]Mainstone RJ. Properties of materials at high rates of straining or loading.

Materials and Structures 1975; 8(2): 102-116.

[47]Zielinski AJ, Reinhard HW, Körmeling HA. Experiments on concrete under

repeated uniaxial impact tensile loading. Materials and Structures 1981; 14(3):

163-169.

[48]Rostasy FS, Scheuermann J, Sprenger KH. Mechanical behaviour of some

construction materials subjected to rapid loading and low temperature. Beton

werk Fertigteil Technik 1984; 50(6): 393–401.

409

410

411

Figure and table captions

412

Figures

414 **Fig. 1** Structure of CRTS I track system

415 **Fig. 2** Vibration acceleration measurement

416 **Fig. 3** Stress-strain curve of CA mortar and Portland cement mortar

417 **Fig. 4** DIF of compressive strength versus strain rate

418 **Fig. 5** SEM analysis of CA mortar

419 **Fig. 6** DIF of compressive strain versus strain rate

420 **Fig. 7** DIF of elastic modulus versus strain rate

421 **Fig. 8** Vibration acceleration - time curve of the impact specimen

422 **Fig. 9** Vibration acceleration-time curve of the steel board under the impact object

423 **Fig. 10** Specimens after impact

424

Tables

426 **Table 1** Impact resistance times of CA mortar and concrete