Construction and Building Materials 139 (2017) 64–80

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Energy absorbing system made of high performance concrete

Petr Hála [a,*], Radoslav Sovják [a], Michal Frydrýn [b], Tomáš Mičunek [b]

[a] Experimental Centre, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic
[b] Department of Forensic Experts in Transportation, Faculty of Transportation Sciences, Czech Technical University in Prague, Horská 3, 128 03 Prague 2, Czech Republic

HIGHLIGHTS

- The energy absorbing system (EAS) made of HPC is designed.
- Full and reduced scale impact test and quasi-static tests are performed.
- Material model and numerical simulation is presented for all specimens.
- Verification of the numerical model with experimental outcomes is carried-out.
- Reasonable deceleration of the impact cart was achieved using HPC-EAS.

ARTICLE INFO

Article history:
Received 4 August 2016
Received in revised form 4 January 2017
Accepted 8 February 2017

Keywords:
Energy absorbing system
High performance concrete
Explicit dynamics
LS-DYNA
Continuous surface cap model

ABSTRACT

This paper is devoted to the experimental development of a high load bearing energy absorbing system (EAS) made of high performance concrete (HPC). The HPC investigated in this study was a self-consolidating concrete with fast strength development which did not require heat curing or special mixing techniques. It was also an inherently very dense material which lead to the excellent environmental resistance and resulted in the long term durability. The proposed EAS was subjected to the thorough testing and its functionality was verified under impact and quasi-static loading. Numerical simulations were compared with the experimental data and good agreement was obtained. It was demonstrated that it is possible to develop an energy absorbing system made of high performance concrete with controlled impact force and deceleration. This demonstration together with load bearing capability and long term durability, predetermined the developed EAS for wide range of applications including those where currently manufactured energy absorbers cannot be applied.

1. Introduction

1.1. Motivation

There has been an increase in the number of vehicles due to advances in transport technology, which inevitably led to the increase in number of the traffic accidents. Over the years, safety features such as restraint systems, airbags or crumple zones were introduced and became an integral part of vehicles. Another important strategy to increase road safety was to prevent a collision of a vehicle with non-deformable objects by protecting the object with an energy absorbing system (EAS) [1]. Many energy absorbers are made of aluminium [1] or aluminium foam [2], high-strength carbon fibres embedded in an epoxy resin [3], glass fibre/epoxy laminated composites [4], metallic materials such as thin-walled round tubes [5] or bamboo [6]. Most of these systems have a limited lifetime in harsh environmental conditions and may therefore fail to preserve their functionality during the service life of the structure to be protected, i.e. bridge columns, culverts, etc. In this paper a new energy absorbing system made of high performance concrete is proposed with suitable energy absorbing properties and a service life exceeding 75 years in accordance with the expected lifetime of structure [7].

The latest concrete safety barrier developed was proposed by Shen et al. [8]. Their research investigated a no-fine concrete with alkali-activated slag. The concrete barrier was designed to break into very small fragments during impact and its high energy absorption ability was reported.

1.2. Research significance

Applications of existing energy absorbers are limited with respect to their price, durability, dimensions or load-bearing

* Corresponding author.
E-mail address: petr.hala@fsv.cvut.cz (P. Hála).

http://dx.doi.org/10.1016/j.conbuildmat.2017.02.048
0950-0618/

capabilities and many objects close to roads or waterways are still insufficiently protected or even unprotected. This situation is alarming as documented by traffic accidents statistics [9] recorded in the Czech Republic: the collisions of vehicles with non-deformable objects represent one sixth of all the traffic accidents and are responsible for one fourth of all traffic accident victims. Among the non-deformable objects surrounding roads such as trees, traffic lights, billboards or noise protection walls, cross-drainage culverts (Fig. 1) should be highlighted. These objects are especially dangerous as they are hardly noticeable for drivers. Once a car accidentally leaves the traffic lane, it can be directed by the drain ditch straight into the culvert (Fig. 2). Its dangerousness can be significantly reduced by introducing energy absorbing system presented in this paper. The EAS can replace the existing culverts (Fig. 3) and fulfil at the same time the function of the culvert as well as the function of the energy absorber.

Fig. 1. Example of a cross-drainage culvert.

Fig. 2. Collision of a vehicle with cross-drainage culvert.

2. Material

2.1. General remarks

Several researchers stated that HPC has the potential to address the poor condition of the ageing infrastructure [10]. HPC can be characterized as a composite material containing a large volume of cement paste with a low water-binder ratio, high microsilica content and only fine aggregates i.e. smaller than 4 mm [11]. Using additional cementitious materials such as microsilica due to the economic, technical and environmental considerations has become a very common practice in modern concrete construction [12]. HPC has outstanding material characteristics such as self-consolidating workability, very high strength and modulus of elasticity [13] and very low permeability which is the first line of defence against any of the physio-chemical deterioration processes [14] and this results in an excellent environmental resistance [15–18]. Due to its increased resistance to de-icing chemicals and freeze-thaw cycles, HPC will be suitable for utilization in the harsh environment of infrastructure. In addition, it can also be used in the underwater protection of bridge piers. All components of HPC are commonly available in large volumes for a reasonable price and the resulting material can be shaped into various forms, which allows it to be used for EAS and makes it easily adjustable to any possible impacting mass or velocity in order to control impact force and deceleration.

2.2. Mix design

Material composition of HPC used in this study was taken from the design of a multifunctional dry prefabricated cementitious composite material with a rapid strength development originally developed at Czech Technical University in Prague [19]. Focus was on the material durability including the microstructural densification by deliberate gradation of aggregates. No heat curing or special mixing techniques were required during the production process.

All components of the HPC excluding water were initially mixed in the 750 kg capacity mixer for 90 s. This included cement, fine

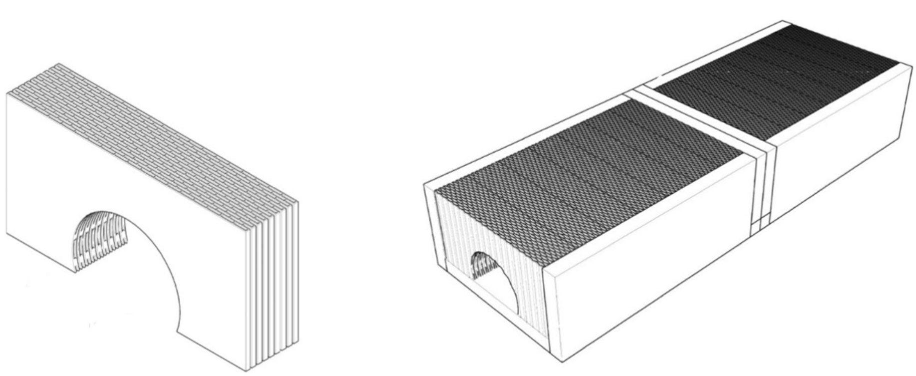

Fig. 3. The proposed energy absorbing system and its possible application.